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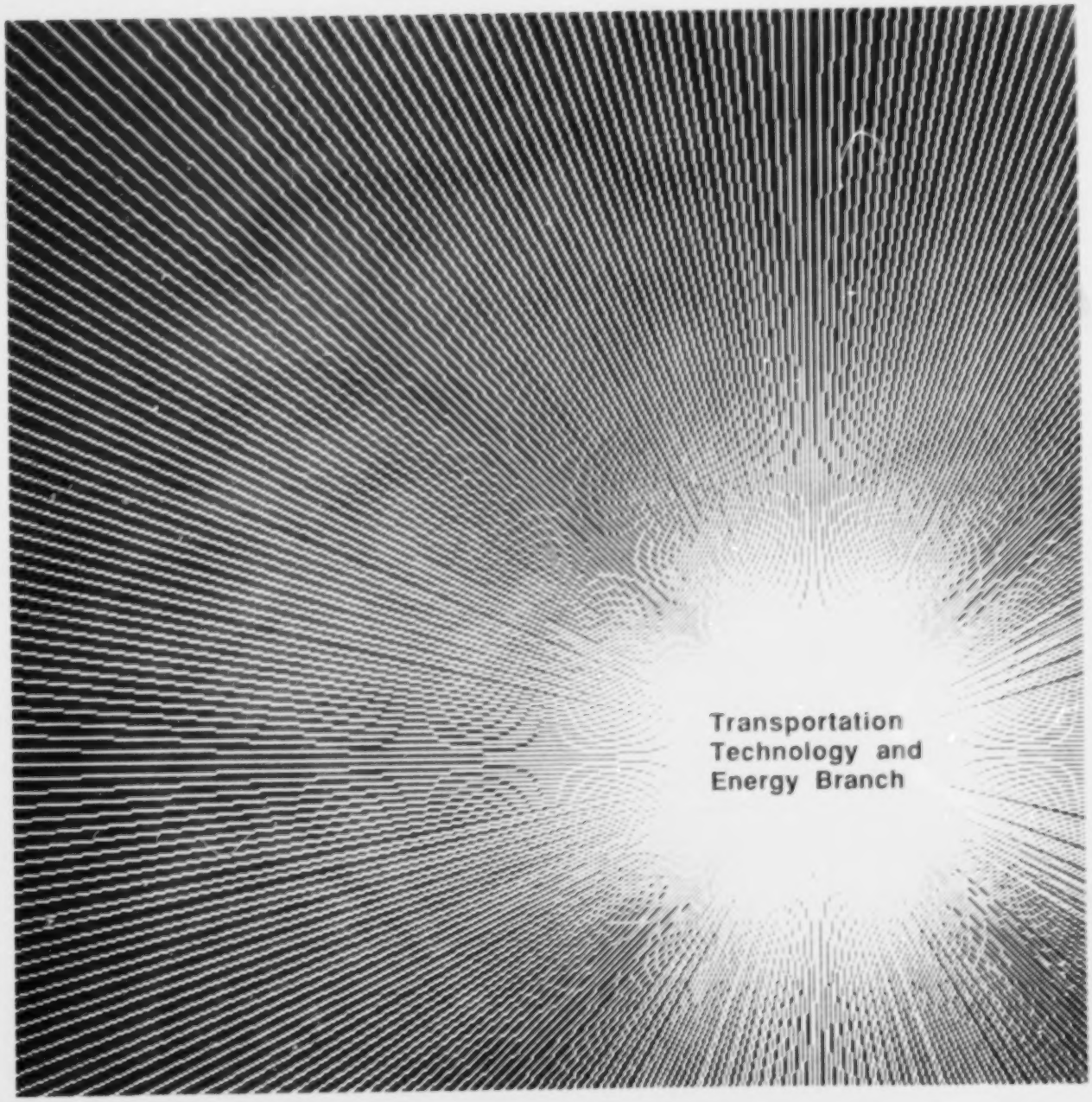

Stability and Control Testing of Two Ministry of Health Ambulances

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Stability and Control Testing of Two Ministry of Health Ambulances

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Abstract: Two Ministry of Health ambulances were tested to determine their braking, steady state and transient handling characterisitics. Both vehicles were tested to their performance limits and were generally found to understeer. The understeer was different for left and right manoeuvres.

Transient tests revealed that the vehicles regained directional control with little effort when forced into a potentially destabilizing manoeuvre. The vehicles were tilt tested to 35° without rollover occurring. When put through a strenuous RCMP drivers course, the vehicles were found to perform comparably to standard RCMP line vehicles once the driver became accustomed to the vehicle.

Key words: ambulance, stability, oversteer, understeer, rollover, steady state, dynamic

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Stability and Control Testing of Two Ministry of Health Ambulances

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The RCMP "VIP" driving course instructors who allowed us the use of their course and experience in a qualitative assessment of the ambulances.

EXECUTIVE SUMMARY

The operation of ambulance services in Ontario is managed by the Ontario Ministry of Health (MOH). The ambulance fleet is currently based on a standard Dodge van chassis with two different internal layouts: a single stretcher version and a dual stretcher version.

Static weighing tests showed that the vehicles possess asymmetric axle loading, both left and right, in addition to fore and aft. Ministry of Transportation (MTO) and MOH personnel have assessed cornering performance at low and moderate speeds, and have found that each vehicle, while behaving differently from the other, also showed signs of right turn performance differing from left turn performance.

An ambulance responding to an emergency is exempt from speed limits. Since the ambulance is basically a standard van chassis designed to operate at normal highway speeds, and given the asymmetric handling properties noted, MOH requested that MTO conduct a series of static and dynamic tests to determine the handling characteristics of the vehicles.

The vehicles were tested to identify their stability and control characteristics by subjecting them to standard automotive tests and test track manoeuvres. Each vehicle was tested at four load conditions. The data were analyzed to show trends in vehicle behaviour for both left and right turn manoeuvres at various speeds as a guide to predict stability thresholds.

The center of gravity was generally found to the left of the vehicle centerline and the vehicles resisted roll over up to 37° on a tilt table. Scuffing of the rear right wheel of the dual stretcher ambulance on the chassis during chassis roll was noted, and spring keepers on the rear leaf springs had a propensity to break and fall off the vehicle during aggressive manoeuvres.

In the steady state tests, both vehicles exhibited progressive understeer up to 0.6 g lateral accelerations, at which point sliding prevailed. In all cases, the vehicles recovered to complete the course with little attendant weaving or oscillation.

The vehicle yawed consistently in the same direction during braking. This was predictably consistent and consistently worsened with speed and surface friction loss.

In a comparison between modulated and wheels locked during braking, it was found that road conditions determined the best braking technique. The tire wear state, within the bounds of MOH operating policy, did not affect overall braking or handling performance. The load status of the vehicle did not have a significant or predictable effect on the steady state, transient handling or braking characteristics of the test vehicles.

1/ INTRODUCTION

The Ontario Ministry of Health (MOH) manages the operation of ambulance services in Ontario. The fleet operated by MOH is made up of standard 8900 GVW Dodge van chassis. These are purchased by the Ontario Ministry of Transportation (MTO) through the government acquisition process and then modified, by MOH subcontract, to its own standards and specifications. The modification encompasses the manufacture and installation of internal appointments such as cabinets, insulation, partitioning, and fittings, and the installation of medical equipment.

Two basic internal layouts are currently in use, each possessing specific stowage and space allotment requirements. These layouts, as shown in Figure 1, are a single stretcher arrangement which can accommodate a crew/patient complement of seven, and a dual stretcher version that can accommodate a crew/patient complement of six. Once a vehicle is prepared as a single or dual stretcher ambulance it stays in that configuration for its operational life.

The two layouts possess equipment stowage and stretcher placement properties suited to its requirements and space availability. Provision for crew seating, stretcher positions, oxygen bottle placement, spare tire placement, and medical storage are different for the two vehicles; hence, the mass distributions of the two vehicles are also different.

Static weighing tests conducted by MOH showed that the vehicles possess non-symmetric axle loading, both left and right, in addition to fore and aft. MOH personnel had qualitatively assessed the cornering performance at low and moderate speeds and found that each vehicle, while behaving differently from the other, also showed signs of right turn performance differing from left turn performance. This was also evident in a similar assessment by MTO staff.

An ambulance responding to an emergency is exempt from speed limits by Section 109(12)(c) of the Highway Traffic Act. They can be, and are, operated at speeds up to about 160 km/h in these conditions. Since the ambulance is basically a standard van chassis designed to operate at normal highway speeds, and given the fact that non-symmetric handling properties were noted, the Ministry of Health requested MTO to conduct a series of static and dynamic tests to determine the handling and stability characteristics of the vehicles.

The basis for this request was that essentially a similar chassis has been used for the past 10 years, and during that time the weight of fittings and equipment had increased significantly. The tests would provide insights into the stability and control characteristics of the ambulances, to provide information for MOH and MTO's Fleet Administration Office to refine vehicle interior specifications and assess the growth potential remaining in the current chassis. The work was also expected to be useful to MOH in developing a driver education program.

2/ OBJECTIVES

The objective of the test program was to identify the stability and control characteristics of the ambulances by subjecting them to standard automotive tests and test track manoeuvres. This was accomplished by instrumenting the test vehicles with transducers for recording vehicle response data and then driving the vehicle onto a prescribed course and conducting a single manoeuvre at progressive speeds or degrees of aggression until response trends showed characteristic behaviour patterns. The tests were conducted to a point as close to the limits of vehicle stability as was deemed safe by the test staff. The test program was designed to subject each vehicle to identical dynamic tests designed to reveal the steady state and transient response characteristics of the vehicles. Each vehicle was tested with four load conditions. Two states of tire wear were also examined. The data were analyzed and reduced to show trends in vehicle behaviour for both left and right manoeuvres at various speeds and used as a subjective guide to predict stability thresholds.

3/ TEST PROGRAM

3.1/ Test Vehicles

The Ministry of Health supplied a single and a dual stretcher ambulance for testing by MTO. The vehicles were supplied with medical and stretcher equipment installed and set up test ready. The vehicles were prepared such that the more stringent of either the manufacturer's or the owner's standards were met or exceeded. The vehicles were then subjected to a Motor Vehicle Safety Certification Test. Each vehicle was supplied with two sets of roadworthy, mounted and balanced tires; one new, one fully worn to MOH minimum tread depth standard. MTO personnel installed equipment to monitor and record the following:

1) Longitudinal and lateral acceleration
2) Sprung mass roll, pitch and yaw angles, and angular velocities
3) Longitudinal speed
4) Chassis attitude angle
5) Steer angle
6) Distance travelled

Instrumentation, control and data acquisition equipment in the drivers compartment and payload area is shown in Figure 2. A specially designed trailing wheel assembly is shown in Figure 3. This provides data to calculate chassis attitude changes during dynamic manoeuvres and hence, chassis sideslip. The second trailing wheel seen in the photograph provides speed and distance data.

MTO used sandbags as ballast to simulate passengers, patients, and crew based on 70 kg per person. Tiedowns for on-board equipment and driver safety harnesses were installed.

Vehicle Designation:	B-350 8900 GVW
Front Track Width:	1.727 m, (68 in)
Rear Track Width:	1.626 m, (64 in)
Wheelbase:	3.254 m, (128.125 in)
Overall Body Length:	5.74 m, (225.88 in)
Overall Body Width:	1.84 m, (79.5 in)
Overall Body Clearance Height:	2.23 m, (87.63 in)
Body Ground Clearance:	0.368 m, (14.5 in)
Frontal Body Overhang:	0.7 m, (27.5 in)
Rear Body Overhang:	1.78 m, (70.25 in)
Body / Chassis :	Dodge Unibody

Single Stretcher Ambulance Identifiers:

V.I.N :	2B7KB33W4GK588451
R.I.N :	020806951

MOH Identifier : 86-51

Dual Stretcher Ambulance Identifiers :
V.I.N : 2B7KB33W3GK542156
R.I.N : 020806951
MOH Identifier 86-09

Tires and Rims:

Tires : Michelin Radial 8.75-R16.5 XCA
New tires were "roaded in" for about 600 km prior to testing.
Tread depth new : 10.3 mm (13/32 in)
Tread depth worn: 4.0 mm (5/32 in)
OEM's recommended air pressure for application:
Front: 385 kPa (55 psi)
Rear : 420 kPa (60 psi)
Manufacturer's recommended pressure: 525 kPa (75 psi)
with single tire load not exceeding 1218 kg (2680 lb)

Rims : Budd Automotive 16.5 X 6.75 riveted spoke design
8 bolt pattern with a maximum load rating of 1455 kg (3200 lb)
and 560 kPa (80 psi) tire air pressure.

Suspension Systems

The suspension systems are shown in Figure 4. There is an independent front suspension of short and long wishbone design with a coil spring over a shock absorber mounted between the chassis and a lower member. The spindle assembly is mounted between upper and lower ball joints. Additional roll resistance is provided through a transverse torsion bar connected between the left and right unsprung components. The upper control arm is a single piece "A" arm. The lower control arm is a formed steel link with a locator rod that forms a virtual "A" arm or wishbone. All chassis mounts for the suspension and torsion bar are rubber bushed. Spring collapse load is 8.46 kN (1900 lb). At low loads, the suspension provides positive kingpin inclination and positive camber. Suspensions "bottom" on a rubber snubber after approximately 50 mm (2 in) of vertical wheel travel, or approximately 4° roll at low vertical load.

The rear suspension is non-independent. The rear axle is of beam design, connected to the chassis by two longitudinal leaf spring clusters. The chassis connections are rubber bushed and longitudinal spring motion is provided by rear spring shackles. Shock absorbers are mounted in two places on the axle with a negative inclination angle. The suspension system is symmetric. Lateral axle location is provided by leaf spring lateral compliance bushings and lateral spring flexibility. The maximum design crush load for the leaf springs are 13.8 kN (3100 lb). The leaf springs on the test vehicles showed near neutral or slight negative camber. The suspension "bottoms" on rubber snubbers at approximately 86 mm (3.4 in) of vertical travel or approximately 9° roll at low vertical load.

Power Train
The power train is shown in Figure 5.

Engine :	Dodge B3L13, 5.9 L, (360 cu.in.), 180 hp
Transmission :	Dodge 727, 3-speed Heavy Duty with Lock-up
Differential :	Dodge 3.73:1, semi-floating axle, limited slip
Drive Shaft :	Standard configuration, two universal joint design, slip joint at transmission

3.2/ Test Site

The testing was conducted at the Ontario Ministry of Transportation Commercial Vehicle Test Facility located 50 km north of London, Ontario in Huron Industrial Park, and at the National Research Council tilt table in Ottawa, Ontario.

The test track is a former airfield runway 1000 m long by 50 m wide. It has a smooth asphalt test area, or skidpad, approximately 350 m long with a smooth approach 150 m long. The test area includes a high-friction surface 150 m long with a dry skid number of 96, and a low-friction surface 200 m long with a wet skid number of 18-24. A sprinkler system can maintain a wetted surface on the skidpad for low-friction testing. There is also a curved track, radius 87 m, entering the skidpad area with an approach from a run up area. The low-friction surface is abutted by smooth shoulders in case a loss of control results in the vehicle sliding off the skidpad. There is also a low-friction lane on the approach which can be utilized as a split-friction surface.

The test facility has 2000 square meters of workspace for vehicle preparation, experimentation, set up, and storage. It includes basic shop facilities, an electronics lab, video lab, office space, and a ground station for data acquisition and processing.

The tilt table is operated by the National Research Council (NRC) at the Vehicle Dynamics Laboratory in Ottawa. The table is capable of tilting to an angle of 35°.

The static tests described in the next section were done inside the test facility building and at NRC. The dynamic tests were conducted on various portions of the test areas. There was no on-highway testing.

3.3/ Static Tests

The static tests determine basic vehicle parameters and physical properties that may aid in understanding and predicting stability and control characteristics of the vehicle. The following static tests were conducted. The test details are outlined in subsequent sections.

1) Determination of front suspension vertical suspension characteristics
2) Determination of rear suspension vertical suspension characteristics
3) Determination of front and rear suspension roll characteristics
4) Determination of center of gravity locations for:
   - Case #1 – Two Crew
   - Case #2 – Three Occupants
   - Case #3 – Four Occupants
   - Case #4 – All Positions Occupied

The position of the crew for each load case, and the corresponding wheel loads and center of gravity positions are shown in Figures 6 and 7.

The vehicle was tilt tested up to the table limit of 35°. Wheel lift-off did not occur, therefore, the vehicle did not achieve roll over. The data collected was used to determine center of gravity location and roll stiffness. A typical tilt test is shown in Figure 8.

3.4/ Dynamic Tests

These tests are designed to discover the vehicle's response to lateral acceleration, or sideforce, while in motion. These are predominantly curved path tests and are broken down into steady-state and transient tests. The steady-state tests measure the directional control properties of the vehicle when a steady steer input is applied and the vehicle is allowed to stabilize. This is done at progressively increasing steady speeds, to monitor the effect of increased lateral acceleration. The transient tests examine the behavioural tendencies of the vehicle as it progresses between steady states. These tests are designed to reveal the vehicle's propensity to slide laterally or yaw at various speeds, lateral accelerations, and steer angles.

Handling, or dynamic response to input is generally measured by the vehicle's rate of change of sideslip angle for a given steer angle at varying lateral accelerations. Put simply, it is a comparative measure of the vehicle's front and rear lateral sliding speed. A sideslipping vehicle can sideslip in three different manners.

Understeer is when the sideslip of the front tire set is increasing faster than the rear tire set. This is often called "plowing" with the effect that the driver has to increase steer angle to maintain a desired path. This is predominantly a stable regime and for this reason, most North American vehicles are designed to understeer under high roll and high sideloading conditions. A speed associated with understeer is the "Characteristic Speed". This is the speed at which, for a given radius, the steer angle of the steering wheels must be twice that of the theoretical steer angle required to traverse the circular course.

Neutral Steer is where the vehicle is sideslipping with equal rates on both the front and rear axle set. This normally only occurs for short periods of time.

Oversteer occurs when the sideslip rate of change of the rear tire set is larger than that of the front. The vehicle tends to slide out at the rear, and can culminate in a spin. This condition is highly unstable and very undesirable for road vehicles. A speed associated with oversteer is the "Critical Speed" which is the speed at which zero relative steer is required to maintain the circular trajectory of the test course.

The tests outlined in this section are designed to measure understeer/oversteer responses. The first three are standard tests designed to determine the steer response characteristics of the vehicles. The last two are intended to represent manoeuvres that typify an ambulance operational scenario. Each set of data was analyzed to determine the relative stability pattern of the vehicle. These tests were as follows.:

1) Constant Radius Test
2) Constant Steer Angle Test
3) Step Input Transient Response Test
4) Spiral 90° Turn
5) Obstacle Avoidance

All tests were performed in both left and right directions, with new tires, and four crew/passenger loads. All tests were performed on a dry asphalt surface, with surface wind less than 25 km/h .

The Constant Radius Test, Constant Steer Angle Test, and the Step Input Transient Response Test are based on SAE XJ266, "Proposed Recommended Practice, Passenger Car and Light Truck Control Response Test Procedures." Minor deviations were made to accommodate vehicle and space restrictions.

3.5/ Brake Application Tests

These tests measure primarily the vehicle yaw stability while undergoing rapid and modulated brake applications. The tests were performed in a straight line course on wet, dry, and split-friction surfaces. The quantitative measure of stopping distance was recorded. The qualitative measures of yaw stability such as final yaw angle and direction of slide were also recorded.

Prior to brake testing, the brake pads were instrumented and burnished. This was done in accordance with SAE J843d, "Recommended Practice, Brake System Road Test Code-Passenger Car and Light Duty Truck."

3.6/ Test Matrix

Static Tests

Objective	Single Stretcher Case#1	#2	#3	#4	Dual Stretcher Case#1	#2	#3	#4
Center of Gravity	X	X	X	X	X	X	X	X
Front Heave Characteristics	X				X			
Rear Heave Characteristics	X				X			
Roll Characteristics	X				X			

Brake Tests

Objective	Single Stretcher Case#1	#2	#3	#4	Dual Stretcher Case#1	#2	#3	#4
Low-Friction Worn Tires								
- Abrupt	X	X	X	X	X	X	X	X
- Modulated	X	X	X	X	X	X	X	X
High-Friction Worn Tires								
- Abrupt	X	X	X	X	X	X	X	X
- Modulated	X	X	X	X	X	X	X	X
Split-Friction Worn Tires								
- Abrupt	X	X	X	X	X	X	X	X
- Modulated	X	X	X	X	X	X	X	X
Low-Friction New Tires								
- Abrupt	X	X	X	X	X	X	X	X
- Modulated	X	X	X	X	X	X	X	X

Objective	Single Stretcher Case#1	#2	#3	#4	Dual Stretcher Case#1	#2	#3	#4	
High-Friction New Tires									
- Abrupt	X	X	X	X	X	X	X	X	
- Modulated	X	X	X	X	X	X	X	X	
Split-Friction New Tires									
- Abrupt	X	X	X	X	X	X	X	X	
- Modulated	X	X	X	X	X	X	X	X	
Spiral Right									
-Worn Tires					X			X	
-New Tires	X	X	X	X	X	X	X	X	
Spiral Left									
-Worn Tires					X			X	
-New Tires	X	X	X	X	X	X	X	X	
Constant Steer Right									
-Worn Tires					X			X	
-New Tires	X	X	X	X	X	X	X	X	
Constant Steer Left									
-Worn Tires						X			X
-New Tires	X	X	X	X	X	X	X	X	
Constant Radius Right									
-Worn Tires						X			X
-New Tires	X	X	X	X	X	X	X	X	
Constant Radius Left									
-Worn Tires						X			X
-New Tires	X	X	X	X	X	X	X	X	
J-Turn Low Speed Right									
-Worn Tires						X			X
-New Tires	X	X	X	X	X	X	X	X	
J-Turn Low Speed Left									
-Worn Tires						X			X
-New Tires	X	X	X	X	X	X	X	X	
J-Turn High Speed Right									
-Worn Tires						X			X
-New Tires	X	X	X	X	X	X	X	X	

Objective	Single Stretcher Case#1	#2	#3	#4	Dual Stretcher Case#1	#2	#3	#4
J-Turn High Speed Left								
-Worn Tires						X		X
-New Tires	X	X	X	X	X	X	X	X
Evasive Manoeuvre Right								
-Worn Tires						X		X
-New Tires	X	X	X	X	X	X	X	X
Evasive Manoeuvre Left								
-Worn Tires							X	X
-New Tires	X	X	X	X	X	X	X	X

3.7/ Test Descriptions

3.7.1/ Measure Front Suspension Heave Characteristics

This test determines the total vertical spring characteristics of the front suspension. It was done to evaluate the suspension's ability to support and share the load. It was measured by loading the front end of the vehicle with ballast and then raising it with a floor jack. Scales were placed under each of the front wheels and the vehicle was lowered slowly onto the scales. Scale loads were plotted against wheel/chassis displacement at each wheel. The results of the test were used to verify that the suspensions were operating free from binding or interference, and in a uniform manner.

3.7.2/ Measure Rear Suspension Heave Characteristics

This test was performed using a procedure similar to that described for the front suspension in Section 3.7.1.

3.7.3/ Measure Front and Rear Suspension Roll Characteristics

This is a measure of the torsional characteristics of the front and rear suspensions about a longitudinal axis of the vehicle. This was done to determine the relative lateral weight transfer across an axle set due to chassis roll. This parameter is very important in handling tests in that the vertical load distribution on an axle set greatly influences the cornering capability of the tires. It is measured in a manner similar to that used in measuring rear heave rate and front wheel rate. One end of the vehicle was loaded with ballast and then that end was jacked clear of the floor. Working with a particular axle set at a time, each wheel was lowered to different heights to represent a particular roll angle. This was done for a progression of roll angles and the vertical force under each wheel was recorded. The left to right vertical force bias was then reduced mathematically to yield roll moment, which was plotted against roll angle. A second set of data was

obtained from the tilt table test for high chassis roll angles, where the roll angle and wheelset loads provided the front and rear roll characteristic.

3.7.4/ Measurement of Center of Gravity Location

This test determines the point in space where the weight of the sprung mass of the vehicle is concentrated. Its location is determined by three coordinates, vertical, longitudinal, and lateral. The location of the center of gravity (CG) is important from a dynamic handling and braking point of view since its position determines dynamic load transfer magnitudes. For each configuration where the CG location was required, the vehicle was weighed with four individual scales to give individual wheel weights. Calculation gave the CG location in the x (longitudinal) and y (lateral) directions. The vehicle was then tilted on the tilt table in both right and left roll directions. The chassis roll angles were measured and the wheel loads recorded and were then used to determine the z (vertical) position of the CG. The ambulance is shown on the tilt table in Figure 8.

3.7.5/ Constant Radius Test

This is a test to determine the steady state oversteer/understeer response of the vehicle by subjecting it to a constant lateral acceleration at a known radius and measured steer angle. The test requires that the vehicle be driven in a circle on a flat surface with measurements taken of steering wheel angle, lateral acceleration, speed, roll angle, and sideslip angle. Data is taken to the limit of control for the vehicle or when space requirements limit. The vehicle was accelerated up to test speed on a constant radius circle and the data collection system was turned on. At a given speed and hence lateral acceleration, steer angle, chassis roll, and sideslip angle were measured and data plotted to show lateral acceleration-sideslip, steer angle relationship. This test provides a means to determine understeer/oversteer responses, characteristic speed (understeer condition), critical speed (oversteer condition), and the vehicle roll gradient. This test was done in both left and right turn directions on an 86.7 m (285 ft) radius skidpad as shown in Figure 9. The speeds commenced at 50 km/h and increased in 5 km/h increments to 80 km/h. It was found that at this speed the vehicle exhibited high roll angles and tire noise was significant.

3.7.6/ Constant Steer Angle Test

Basically this test is an alternative to the constant radius test. It was used to verify and supplement that test for measuring the directional control properties at low speed, high lateral accelerations. The test required that the steer angle be set such that the vehicle followed an 18 m (60 ft) radius curve at low speed, as shown in Figure 10. With the steering held at this angle, the speed was increased very slowly, to minimize transient effects, and readings of lateral acceleration, speed, sideslip, yaw velocity, and steer angle were taken. The test was done at a steer angle of approximately 18°. This steer angle allowed all vehicles to operate at the largest radius possible on a homogenous

surface. The reduced data provides understeer/oversteer responses as a function of trim and characteristic or critical speeds.

3.7.7/ Step Input Transient Response Test (J-Turn)

This test provides both steady-state and transient response data by providing a step input to the steering and measuring the response until steady state is achieved, Figure 11. It is used primarily to determine the nature and duration of the transient responses at various speeds for various inputs. The steer input is a steep ramp input rather than a pure step. The steer displacement was set by using steering wheel markers and verified by steer angle transducers. The duration was governed by the nature of the response and the vehicle's position on the test course. In all cases, steer was held until the vehicle stabilized. The driver approached the test area in a straight line at constant speed and then executed a step steer (steep ramp) input, and held that steer angle until the vehicle achieved steady state. The angle used for the low speed runs was 18°-20° (the same steer angle in the constant steer test). The steer angle used for the high-speed turns was the approximate steer angle measured at maximum speed in the constant radius test. This was done in both left and right directions for two speeds. The speeds were the highest speed attainable in the constant steer test for the low-speed run, and the highest speed attained in the constant radius test for the high-speed run. The transient responses were analyzed to establish response time differences, left and right, and stabilization time. This gives a measure of the vehicle's ability to stabilize once perturbed and indicates left- and right-turn response time differences.

3.7.8/ Spiral 90° Turn Test

This test was used to determine vehicle responses during the execution of a spiral turn. The manoeuvre produces a progressive increase in lateral acceleration on the vehicle and simulates a realistic turn situation. The test measures the transient response of the vehicle while in the manoeuvre. The recorded data includes lateral acceleration, speed, steer angle, roll angle, relative attitude angle, yaw rate, and yaw angle. The vehicle was driven in a straight line, at a constant speed, approaching a marked spiralling lane that exited 90° from the approach ramp, as shown in Figure 12. The spiral caused the vehicle to turn from a straight path to a 36.6 m (120 ft) centerline radius while turning through a 60° angle. The remaining 30° portion of the turn, to egress, is at a constant 36.6 m (120 ft) radius. The length of the spiral trajectory was 76.7 m (251.6 ft) and the constant radius trajectory was 19.1 m (62.8 ft) long. The test was conducted using spirals both to the left and to the right. The data was reduced to show the response history of the vehicle. The test was performed at speeds of 45, 50, 55, 60, and 65 km/h. It was found that at 65 km/h, the vehicles exhibited excessive rear wheel slide, and any speed over 65 km/h would render the data meaningless. A trailing wheel reference run was used with this test to determine slide and tracking characteristics of the vehicle at the various test speeds.

The vehicle was first driven through the course at low speed and a record was made of the sideslip trailing wheel data and steer. The data was distance coded by ground

triggers sensed by a vehicle-mounted photo optical system. Data from higher speed runs were then adjusted to the same distance reference as the reference run. The data from the reference run at each distance point was then subtracted from the data at that same point in the higher speed run. The resulting curves showed the net chassis attitude differences, steering differences, and increase in lateral acceleration at each point as the vehicle progressed through the course. This is used in manoeuvres where the front axle is constrained to follow a specific trajectory, such as the spiral turn and the obstacle avoidance. The technique is useful in qualitatively assessing the effect of speed on steer and chassis attitude in the manoeuvre.

3.7.9/ Obstacle Avoidance

This test is used to determine the vehicle's responses while avoiding an object in its traffic lane. The vehicle approached a lane marker and the driver steered to enter an adjoining lane. After a short distance in this lane the driver returned to the original lane, as shown in Figure 13. The track layout for this test employed a 3 m (10 ft) wide approach lane, an opening of 19.3 m (60 ft) to enter the adjoining lane, an adjoining lane length of 9.1 m (30 ft), and an opening of 19.3 m (60 ft) to reenter the original lane. The test was executed in both left and right directions at speeds of 50, 55, 60, 65, 70, 75, and 80 km/h. Recorded data included lateral acceleration, roll angle, heading, sideslip, relative attitude angle, and speed. A trailing wheel reference run was used with this test to determine slide and tracking characteristics of the vehicle at the various test speeds.

3.7.10/ Abrupt Brake Application

This braking test was used to determine the yaw characteristics of the vehicle while executing a maximum pedal application braking stop. The data recorded included yaw angle, deceleration, lateral acceleration, speed, roll angle, and pitch angle. The vehicle was driven at constant speed and then aggressively braked (full pedal travel for duration of slide). This was done from initial speeds of 50, 65, and 80 km/h on both a low-friction and a high-friction surface, and from 40 and 50 km/h on a split-friction surface. The test was done in both directions on the split-friction surface to allow each side of the vehicle to be exposed to the low-friction portion of the roadway. The test was executed with both new and worn tires.

3.7.11/ Controlled Maximum Performance Braking

This test was a repeat of the abrupt brake application with the exception that the brakes were applied in a progressive, modulated manner so as not to induce wheel lock.

4/ COMPUTER SIMULATION

The vehicle test could only be conducted at speeds up to 80 km/h within the confines of the test area, whereas the ambulance may operate at speeds up to at least 160 km/h on the highway in an emergency. A simulation model was therefore calibrated against actual test results and used to predict vehicle behaviour at higher sideload on the constant radius course.

Since the test runs used to calibrate the simulation were based on the 86.7 m (285 ft) radius skidpad, a similar test course was used in the simulation. The test staff felt that speeds over 80 km/h on the course could result in catastrophic rollover or serious sliding damage as a result of tire wrap-under, suspension bottoming, or component failure. The simulation can provide indications of oversteer/understeer performance at speeds over 80 km/h on the skidpad up to the point of suspension "bottoming." When this occurs, the roll distribution characteristics are substantially altered with an attendant modification in load transfer and hence tire performance.

The simulation model is a steady-state dynamic model designed to show relative fore/aft lateral slide tendencies for various lateral accelerations in a steady turn. The model uses four identical tires, with non-linear characteristics. It allows for lateral load transfer across each axle. Jacking may be applied to an individual wheel to show its effect on left and right cornering properties. Modifiers were used to compensate for the effect of roll induced camber and roll steer. The chassis was divided into sprung and unsprung masses each described by its own coordinate system. The lateral acceleration was applied progressively and the cornering properties were measured.

The model does not include the effects of moment of inertia, or rate controlled suspension variables. It was designed to reflect steady-state performance on a constant radius turn at constant speeds. It was used to measure reactions in the speed range where actual testing was not feasible.

The output from the simulation run was the fore and aft lateral slip angle history for specific lateral accelerations. This was reduced to yield handling curves for the vehicle on the given test course.

5/ OBSERVATIONS

5.1/ Static Tests

5.1.1/ Front and Rear Suspension Heave Characteristics

The heave characteristics are shown in Figure 14. The heave test revealed that there was little difference between single and dual stretcher ambulances. This was expected since both chassis were virtually identical. As Figure 14 indicates, the rear suspension showed a steeper gradient, higher stiffness, than the front. This is typical for a vehicle of this type due to its employment as a general cartage carrier.

5.1.2/ Front and Rear Roll Characteristics

The suspension roll characteristics are shown in Figure 15. The curves show chassis roll angle plotted against total load transfer across the axle. This is the roll angle range normally encountered in everyday driving. The data reveals that the front roll characteristic was similar for both vehicles, while the rear showed a higher roll gradient for the single stretcher version. At higher roll angles, the situation was reversed, giving higher roll stiffness on the front, and differing stiffness left to right. This was detected on the tilt table and is valid for roll angles over 1° to chassis bottoming. The higher stiffness over 1° roll can be explained partially by the low lateral CG displacement, and that at low angles the effect of auxiliary roll stiffness is quite low.

It was found that at roll angles over 4°-5° to the right, an interference problem was detected in the dual stretcher ambulance. At these roll angles, the chassis made contact with the inner sidewall of the right rear tire and caused excessive scuffing and abrasion, as shown in Figure 16. Although most of the noise and smell were due to some undercoating burning off as a result of friction, bare metal was soon exposed on the chassis. This problem became obvious during the dynamic tests since its results could be seen, heard, and smelled. The problem can be attributed to the combination of rear axle lateral displacement and roll. Although lateral displacement was not measured directly, it could be deduced that, due to the design of the rear suspension some lateral displacement was present. The compliance bushings in the rear spring keepers and shackles, and the design of the springs and keepers themselves, suggest that there is some allowance for lateral movement under load. It should be pointed out that the portion of the chassis in contact with the tire is part of the occupant compartment, and not part of OEM design.

Although contact is experienced only at high lateral loadings, damage may not be obvious. The only indication the test crew had of the problem was light smoke issuing from the wheelwell and the odor of burning rubber. These symptoms are not readily apparent to the driver. The damage could accumulate over a period of time from intermittent contact rather than the sustained contact encountered at the test track, and could, therefore, unexpectedly cause a rear blowout.

The vehicles were tilt tested in both directions to the full capability of the tilt table (35°). Neither vehicle rolled so as to engage the restraining devices, hence a rollover could not be achieved. Data was collected on tire loading, load transfers, and roll. The data was used to measure CG coordinates for the various load configurations and chassis roll characteristics. The high roll angle roll stiffnesses were calculated as input for the simulation described in Section 4.

5.1.3/ Center of Gravity Location

The CG locations for all load cases are shown in Figures 6 and 7. The loading of the test vehicles generally placed the CG to the left of the vehicle centerline for all but the single stretcher ambulance, load case #4.

Figure 17 shows the effect of lateral loading on the lightest loaded rear wheel. The data was gathered from tilt table tests. The total chassis tilt angle was converted to effective lateral acceleration by using the tangent of the tilt table angle. The bars commence at a vertical load of 230 kg (500 lb) and terminate when the tire leaves the surface of the table. In almost all cases, a roll to the left, indicating a right turn, caused tire performance loss sooner that a left turn. In the case of the dual stretcher ambulance, the gap between left and right appeared more pronounced, with load case #2 being the greatest. Generally the higher payload tended to allow for higher lateral loading before tire sideforce loss was encountered in right turns. Data from turns to the left did not show significant performance trends with respect to payload.

Although tilt table tests revealed that the rear axle tended to lift first during tilting, photographs of actual high sideload tests, Figure 18, indicated that the front wheels appeared to be on the verge of lift-off. It is suggested that this phenomenon is probably an illusion due, in part, to the effect of high roll-induced camber on the inside wheel, a characteristic of this particular independent suspension. This causes the tire not to ride squarely on the ground and shows some clearance under the outer shoulder; thus exposing the first level of grooves and sipes. The overall appearance may be that of impending lift-off. A close examination of the rear inside tire in Figure 18 (upper photograph) shows very little bulging sidewall as a result of vertical load; hence, a minimal contact length. When this is compared to the somewhat obscured view of the rear outer wheel that appears to be exhibiting lateral deflection and somewhat greater "bulging", a higher vertical loading can be assumed.

The static tests did not reveal any vehicle characteristics that might be expected to inhibit the overall performance of the vehicle during the dynamic portion of the tests.

5.2/ Dynamic Tests

5.2.1/ Constant Radius Test

One of the measures used in quantifying vehicle handling data is the coefficient of understeer. This parameter is a number, that when multiplied by the lateral acceleration gives the comparative lateral sideforce characteristic of the vehicle. For example, a coefficient less than zero indicates that the vehicle is experiencing oversteer – the rear tire slip angles are increasing faster than the front. A coefficient equal to zero indicates that the vehicle is experiencing neutral steer – the front and rear slip angle rates are equal. A coefficient greater than zero indicates that the vehicle is in understeer – the front slip angles are increasing at a rate greater than the rear. The number itself is a measure of the magnitude of the characteristic, so a vehicle with a coefficient of -0.25 is oversteering more than one with a coefficient of -0.10.

Figures 19 and 20 show the coefficient of understeer plotted against lateral acceleration for both vehicles, all load conditions, left and right manoeuvres. The load state of the vehicle did not contribute significantly to a growth of the curves in any particular manner. The envelopes show the overall understeer characteristic and tend to show that the single stretcher ambulance exhibited higher understeer when executing a steady-state left turn. The dual stretcher ambulance tended to show similar characteristics left and right and similar to the right turn characteristic of the single stretcher ambulance. This seems to support the high front right roll stiffness found in the single stretcher ambulance on the tilt table. The higher stiffness would tend to promote higher lateral load transfer at the front; hence, a greater loss in tire sideforce. The effect would be to increase understeer.

The overall slip angle difference envelopes (fore and aft) are shown in Figure 21. The growth of the curves did not suggest a relationship with payload. The curves indicated consistent understeer, with the single stretcher ambulance exhibiting a wider performance band.

The steering response in the constant radius test is shown in Figures 22 and 23. This is a measure of the amount of steer required to follow the constant radius course. The actual steer angle at the roadwheels is divided by the theoretically correct angle for a vehicle of that particular wheelbase operating at the given radius. The neutral steer line, 1.0, signifies that no additional steering is required. It is plotted against vehicle speed.

The dual stretcher ambulance exhibited a pronounced understeer that required increasing steer angles with speed. The left turn was similar to the right. The single stretcher ambulance, however, while showing understeer, indicated that higher steer inputs were required to turn left than right.

The average slip angle vs lateral acceleration curves are shown in Figures 24 and 25. In all cases, the front slip angles appeared larger than the rear, the left larger than the right.

The difference between left and right is more pronounced for the single stretcher ambulance.

Roll stiffness data obtained during the constant radius test is shown in Figures 26 and 27. The overall curve tends to follow the data obtained on the tilt table and static tests up to 2° roll, and validates that portion of the data. The dual stretcher ambulance showed near equal roll rates left and right, while the single stretcher ambulance showed a stiffer right roll rate than left.

5.2.2/ Constant Steer Angle Test

The constant steer test measures steady-state cornering characteristics at low speed. Figures 28 and 29 show the understeer coefficients for both vehicles. In this test, the right turn tends to show the higher coefficient, although the differences left and right appear marginal. The basic differences between this test and the constant radius test are steer angle related. In the constant radius test, the steer progresses until the driver achieves steady-state turning. Steer related idiosyncrasies at various steer angles are reflected in the data. In the constant steer test, the steer angle is held constant, therefore; only the idiosyncrasies associated with that angle are reflected in the data. The understeer difference in this test would be barely perceivable by the driver. The test was conducted until tire noise and high roll rates indicated that the vehicle was nearing its design limits.

Curvature response data are shown in Figures 30 and 31. This is a measure of the growth of one over radius per steer input degree and is known as curvature response gain. Both vehicles possess characteristics that decrease with lateral acceleration increase. This reflects an understeer condition. The dual stretcher ambulance shows similar traits left and right, while the single stretcher ambulance shows an increased understeer in the left turn direction.

5.2.3/ Step Input Transient Response Test (J-Turn)

Response time differences for abrupt steer inputs are shown in Figures 32 and 33. In these tests, the response time is the time elapsed between when the steer action has stopped and the vehicle's reaction has stabilized. In Figure 32, bars to the left indicate a faster stabilization time in left turns than right turns, at low speed. Bars to the right indicate faster responses to the right. The dual stretcher ambulance tended to react faster in left turns. The reaction times were approximately 40% less than for right turns. The single stretcher ambulance showed a similar trait with the exception of load case #4. In this instance, it responded very quickly to the right, comparatively speaking.

In the high-speed test, shown in Figure 33, the dual stretcher ambulance showed similar traits, left and right, the only exception being load case #3 where it reacted approximately 40% quicker to the left. The single stretcher ambulance tended to react quicker in left turns; however, this tendency decreased with load.

The lateral acceleration response decay time is shown in Figure 34. This is the elapsed time between peak lateral acceleration achieved and onset of steady state. It is roughly a measure of the vehicle's ability to stabilize, once perturbed.

In the case of the dual stretcher ambulance, at high speed, the left turn characteristic tended to decrease with load. The right turn characteristic was similar, but rose at the higher load. At low speed, the right turn characteristic tended to rise with load, while the left turn stayed relatively constant.

In the case of the single stretcher ambulance at high speed, the left turn characteristic remained constant while the right turn appeared to increase with load. In the low-speed test, the right and left turns appeared uniform across all load ranges, the right turn characteristic being consistently larger than the left.

5.2.4/ Spiral 90° Turn Test

This test is designed to measure transient response characteristics, and therefore, show the effect of such influences as inertial roll, pitch and yaw properties, shock absorber induced stiffness enhancements, and other responses associated with transient accelerations. The test is designed to reflect handling responses experienced in an actual turn situation. This situation is often seen when the vehicle enters an intersection at a moderate rate of speed and commences a progressively "tighter" turn toward a sidestreet. In the steady-state tests, more pronounced understeer was experienced in left turns, in the spiral test the opposite appeared to be the case.

The data from the spiral turn test are shown in Figures 35 to 38. In the spiral turn test, the vehicle is required to turn through 90° in a decreasing turn radius course. The test is designed to provoke a chassis response through the combination of increasing lateral acceleration, increasing chassis roll, and high steer angles. It is both qualitative and quantitative in assessing the vehicle's ability to follow a given trajectory.

Figures 35 and 36 show the approximate differences in slip angle, front minus rear, as the vehicle progresses through the course at various speeds. This is measured using the technique outlined in Section 3.7.8.

The dual stretcher ambulance data is shown in Figure 35. The performance was similar both left and right; however, there were marginally higher slip angle differences in right turns. The single stretcher ambulance, data shown in Figure 36, exhibited higher slip angle differences in right turns by approximately twice as much. This characteristic indicated that the vehicle appeared more responsive in left turns, although both directions showed understeer. Both vehicles showed an increase in their respective trends with greater speed.

The steer angle for the spiral course is shown in Figures 37 and 38. The dual stretcher ambulance requires marginally higher steer input in right turns, usually by less than 1°.

There does not appear to be any relationship between steer required and payload. Larger steer angles, approximately 50% to 75%, are required for right turns with the single stretcher ambulance.

5.2.5/ Obstacle Avoidance

Data for the obstacle avoidance manoeuvre are shown in Figures 39 to 42. In this test, the vehicle must be steered into an adjacent lane to avoid an imaginary obstacle and return to the original lane. The course geometry was laid out as described in Section 3.7.9 and is shown in Figure 13. Data for these figures are based on the reference run technique described in Section 3.7.8.

The net sideslip difference for the dual stretcher ambulance is shown in Figure 39. The first three load cases show a higher incidence of sliding in manoeuvres to the right, whereas load case #4 has higher sliding in the left manoeuvre. In all cases, the amount of slide increased with speed and the highest slide measurements were at the point of departure from the adjacent lane. The maximum safe speed for this manoeuvre was between 75 km/h and 80 km/h. At this speed the vehicle experienced rear slide upon entrance to the original lane. Although the slide appeared violent, the vehicle was quickly stabilized with minor corrections from the driver. The vehicle in load case #4 appeared to slide more throughout the manoeuvre. The other vehicles had a propensity to increase their slide with distance into the manoeuvre.

The single stretcher ambulance exhibited a higher overall propensity to slide in both directions throughout the manoeuvre. The magnitudes were similar, as shown in Figure 40. The overall amount of slide tended to increase with load. The maximum speed attained was between 75 km/h and 80 km/h. At this speed the vehicle experienced rear slide upon reentry to the original lane. The slide appeared to be excessive but the vehicle stabilized readily with little correction from the driver and continued in a stable manner.

The net steer angle for the dual stretcher ambulance is shown in Figure 41. This vehicle required more frequent, and larger, steer inputs when executing the manoeuvre to the right. The largest net steer peak is with load case #4 where sliding throughout the manoeuvre was experienced.

The net steer angle for the single stretcher ambulance is shown in Figure 42. This vehicle also required more frequent, and larger, steer inputs in manoeuvres to the right.

This was more apparent at the lower chassis loads. The high steer amplitude noted in load case #1, corresponds with the erratic sliding shown in Figure 40, load case #1.

The overall shape of the net steer curves reflect a different steering strategy left and right, for both vehicles. An obstacle avoidance to the right required more assertive action by the driver to remain within course boundaries.

5.3/ Braking Tests

5.3.1/ Low-Friction Surface

Measurements taken on the wetted test surface in the low-friction area revealed a skid number of 24 at 80 km/h. Stopping distances on the low-friction surface are shown in Figure 43. In most cases the single stretcher ambulance tended to stop in a slightly shorter distance than the dual stretcher ambulance. The differences between the vehicles' stopping distances became most apparent at the higher approach speeds. Load case did not have a significantly consistent effect on stopping distance.

The amount that the vehicle yawed, or rotated, during abrupt braking on the homogenous low-friction surface is shown in Figure 44. In almost all cases the vehicle rotated counterclockwise, or toward the passenger side. The range of the maximum yaw angle and magnitude, increased with approach speed.

The data from Figure 44 are shown broken down by load case in Figure 45. There does not appear to be a correlation between the load case and the resulting yaw angles. The dual stretcher ambulance tended to yaw farther than the single stretcher ambulance at the higher approach speeds.

5.3.2/ High-Friction Surface

The stopping distance comparison on the high-friction surface is shown in Figure 46. The single stretcher ambulance stopped slightly shorter in most cases. The load case did not appear to play a significant roll in the stopping distance, nor did the tread depth of the tires. On this surface, all vehicles stopped in a comparatively straight manner exhibiting less than 5° total yaw.

5.3.3/ Split-Friction Surface

The maximum average yaw angle, based on averaging new and worn tire data achieved on a split-friction surface, is shown in Figure 47. In all but one case, the vehicles yawed more when the slide was counterclockwise. The yaw was always toward the lowest friction lane, but always more so when the right wheels were in the low-friction lane. A direct relationship between the load status and yaw response was not apparent.

5.3.4/ Effect of Modulation and Other Observations

Two brake-application techniques were employed in this test series, abrupt and modulated. The comparison between modulated and abrupt braking technique, for various loads, on low- and high-friction surfaces, is shown in Figure 48. With the driver using a modulated pedal action, it was always possible to stop in a shorter distance than lock-up on the low-friction surface. When this technique was used on the high-friction surface, stopping distances were longer than when lock-up occurred.

Examination of the stopping distance and yaw angle data revealed no apparent correlation between response and tire tread depth for the tread depths examined.

The effect of worn tires on the overall performance was examined directly in the braking tests and indirectly during the handling tests. The tire states examined were new, and fully worn to Ministry of Health minimum standards, 5/32" tread depth. It was found in both braking and handling tests that differences in performance could not be clearly assigned to the tire state. The tread and sipe depths were sufficient to discharge excess water in the contact patch during braking, and to render no consistent deviation in performance. Both vehicles hydroplaned and decelerated until hydrodynamic lift reduced sufficiently to cause contact with the surface. The wetted surface was controlled to avoid an accumulation of excess water on the roadway. In actual abrupt stopping situations on highways, the stopping distances and yaw characteristics may be somewhat different due to the particular roadway surface and environment.

It was noticed during abrupt braking tests that the engine would stall intermittently. When this happened, it was accompanied by what sounded like an attempt by the transmission to downshift and the sensation that the application of the brakes was reducing engine speed. The consensus of the test staff was that the automatic transmission lock-up system was not releasing fast enough to break the power connection between the engine and driveline. This happened on about 5% of the abrupt braking runs. Such an occurrence, if the diagnosis is correct, would tend to compromise brake effectiveness over the long term and reduce overall brake efficiency.

5.4/ Computer Simulation

A sketch of the mechanical equivalent of the Constant Radius Simulation Model and the input parameters is shown in Figure 49. The responses and comparisons are shown in Figures 50 and 51.

The model was calibrated using slip angle data from the constant radius tests up to 0.5 g. The curves in Figure 50 indicate that the vehicle should understeer as long as the suspension systems maintain linearity. This is expected to continue from where actual data ends (0.5 g) to approximately 0.7 g. At this point, it is expected that either front or rear suspension bump stops will interfere with suspension travel and modify the roll characteristic of the vehicle. The onset of bump stop interference is related to ride height and, hence, chassis load.

This model was used to predict the effects of higher lateral acceleration on steady-state cornering only and should not be construed as an accurate predictor of cornering behaviour in the higher sideload ranges. Data from Figure 50 and 51 indicates the general trend of the predicted behaviour and compares it to actual data. All data, both real and simulated, tends to reflect understeer without any apparent trend reversals.

5.5/ General Observations

Measurements taken during the static tests revealed that at specific ride heights and trim, the front suspension virtual roll center was below ground level. The measured locations are shown in Figure 49. This caused a sensation of sway rather than roll at the driver's station. This sensation became noticeably apparent to the test driver when the vehicle was subjected to a series of continuous manoeuvres.

In addition to the formal tests described, the ambulances were driven through the Royal Canadian Mounted Police "VIP" driver test course. This instructional course is for commissioned officers to become accustomed to the high-speed behaviour of their vehicle. It involves accelerating turns, obstacle avoidance, wet track serpentine manoeuvres, gravel road braking techniques, and low-speed precision driving.

After a brief practice period for the test driver to become accustomed to the ambulance's handling traits, it was found that the ambulance was able to complete the course at speeds similar to the police cars. This could be achieved in spite of the fact that the ambulance's front axle was wider than the police car's, had a longer wheelbase, and more rear overhang.

The test load cases, #1 through #4, required that ballast loads be secured in the vehicle to simulate human occupants. During a spiral turn, a securing strap failed and caused a load shift in the patient compartment. The attendant noise and load shift was felt by the driver and the vehicle required a minor steer correction to maintain continuity. In real-life situations, it is expected that load shifts are more the rule than the exception. Although the shift was not sufficient in itself to cause a catastrophic response, it may have a disarming effect on a driver that may trigger an inappropriate response.

6/ DISCUSSION

The load placements in the test vehicles generally yielded a CG to the left of the vehicle centerline for all but the single stretcher ambulance, load case #4. This characteristic, in principle, generates increased cornering capability in left turns due to lateral load transfer resulting in near equal tire loads during turning. Small CG offsets produce small differences.

The tilt table data revealed that the vehicle resisted roll over up to the maximum table angle of approximately 35°. This implies that the chassis can be subjected to lateral acceleration in the magnitude of 0.70 g (tangent of 35°), without roll over. This margin can be drastically reduced and the vehicle rolled at lesser sideloads if extenuating circumstances such as hitting a curb or blowout occur.

Actual test runs were conducted up to 0.7-0.8 g without noticeable roll over tendencies. The vehicle slid laterally at these loads and would have almost certainly rolled over if a blowout had occurred or if it slid and the tires hit an unforgiving obstacle such as a pothole, curb, or soft shoulder.

The problem of the rear right wheel of the dual stretcher ambulance contacting the chassis is addressed in Ontario Regulation 741/81, The Highway Traffic Act, Paragraph 5(b), which reads in part:

> "A tire fitted on a vehicle shall not contact any vehicle component so as to affect the safe operation of the vehicle."

Although contact was only made at high roll angles and lateral accelerations, it is still a problem that if left unchecked, could have disastrous results.

Spring keepers on the rear leaf springs had a propensity to break and fall off the vehicle during aggressive manoeuvres. This was remedied in part, by using water hose clamps as spring keepers. The high loading encountered in the tests exceeded the safe stress levels of the original keepers. Although the keepers are OEM parts, their loss would not significantly contribute to, nor detract from, overall vehicle performance. The effect would be to alter the rebound stiffness of the leaf spring when the vertical loads are in the leaf separation range, i.e., just prior to actual lift-off. The keepers should, however, be brought to the attention of the manufacturer since their loss allows excessive moisture and foreign material to enter the laminates, which causes losses in spring performance and premature failures.

An examination of steer data calibration revealed that steer measurements, performed on a Chrysler dealer's alignment machine prior to testing, showed non-symmetric steering characteristics. The discrepancies were minor, likely due to not centering the Pitman Arm when the last alignment was done. This had a minor effect on the data and would cause the driver to notice what could be perceived as non-symmetrical steering.

In the steady-state tests, both vehicles sufficiently demonstrated progressively increasing understeer. This phenomenon was partially expected due to the higher forward roll stiffness distribution and front roll camber effects. Although the understeer rates were different, left to right, the lowest was still indisputably within the understeer definition. Both vehicles displayed lateral slide and excessive tire noise at about 0.6 g, indicating that sliding rather than roll over would be the mode of instability experienced in these tests.

The bias understeer of the single stretcher ambulance can be traced to the high front right roll stiffness bias encountered. Although the cause of this phenomenon is not readily apparent, it did show up, in part, in steady-state roll data and on the tilt table roll characteristic. An investigation of the front suspension did not reveal any apparent interferences, binding, or damaged components that would cause such an occurrence. A high front roll stiffness generally causes higher lateral load transfer across the front axle set than its rear counterpart; hence, causes a larger reduction in front tire sideforce capability. This increases understeer. The effect is augmented at high roll angles by the roll induced camber of the front roadwheels as compared to the relatively low roll induced camber of the rear roadwheels.

The constant radius and constant steer test are steady-state tests and, therefore, do not reflect the modifying effect that shock absorbers and inertia have on abrupt handling. It can be assumed, however, that the shock absorbers would have the effect of transferring the roll stiffness distribution aft; hence, promoting less understeer. This can be deduced from the fact that both vehicles use identical shock absorbers, both front and rear, and that the shock spacing and collapse angle are similar fore and aft. This would tend to increase the front and rear roll stiffness uniformly, thus, reducing the proportional difference fore and aft.

The object of the transient tests is to measure the vehicles' responses to inputs that cause the vehicles to follow a particular course or trajectory. Since these tests are dynamic they show the cumulative effect of such parameters as inertial roll, pitch and yaw moments, shock absorber induced stiffness enhancements, and any other response associated with planar accelerations. In these tests, both vehicles exhibited progressive understeer up to 0.6 g. At this point, excessive sliding prevailed. At the higher speeds in the obstacle avoidance test, tire lift-off was noted on several occasions when natural roll frequency appeared to coincide with lateral acceleration input. In all cases the vehicles slid laterally and then stabilized. This was due to the low center of gravity height/track width ratio of the vehicle.

The reason that the vehicle yawed consistently in the same direction during braking cannot be directly attributed to a particular cause; several factors tend to complicate the assessment. The basic cause of the slide was that a yaw moment exists. This was likely brought on by unbalanced left and right longitudinal tire forces and, to a lesser degree, test track crossfall. Causes for the former are lateral center of gravity position, suspension pitch and roll coupling reactions, torsional engine breaking reactions, to mention a few.

The specific why and wherefore are beyond the scope of this report. It is important to know that the phenomenon is predictably consistent, and consistently worsens with speed and surface friction loss.

In a comparison between modulated and abrupt braking it was found that road condition determined the best braking technique. On low-friction surfaces, modulated pedal action caused shorter stops than wheel lock-up, with the added bonus of directional control during stopping. On dry asphalt, wheel lock-up yielded shorter stopping distances.

The results noted during the transient test phase were apparent in a simulated pursuit conducted on the RCMP VIP driver test course. The vehicle did exhibit asymmetric handling traits but remained within an understeer regime.

7/ CONCLUSIONS

MTO has tested two MOH ambulances.

A tilt test up to the limit of the tilt table, approximately 35°, was insufficient to cause roll over in any of the load cases examined.

Three mechanical problems were detected during the test program that may have affected performance:

1) Engine stall during abrupt braking.
2) Loss of spring retainer clips (keepers) on rear leaf springs during aggressive manoeuvres.
3) Right rear tire scrubbing on body/chassis component on the dual stretcher ambulance during manoeuvres involving rolling to right, which contravenes the Highway Traffic Act.

The tire wear state, within the bounds of MOH operating practice, as used in this test, did not significantly affect overall braking and handling performance. The load status of the vehicles tested did not have a significant or predictable effect on the steady state, transient handling, or braking characteristics of the test vehicles. Unsecured loads, when shifted, caused the driver to make minor steer corrections and had a distracting effect. During braking manoeuvres where a slide was impending, the vehicles consistently yawed counterclockwise, and in so doing compromised adjacent traffic lanes. There was no discernible tendency to roll during a combined sliding/braking deceleration on a low-friction surface. Abrupt stops from over 65 km/h on homogenous low-friction surfaces tended to cause rotations in excess of 90°, thereby precluding any chance of a graceful recovery. On split-friction surfaces, abrupt stops from over 50 km/h had the same effect. On high-friction surfaces, the vehicle slid to a controlled stop from approach speeds up to 80 km/h with very little or no rotation. In most cases the vehicle stayed within its lane, but on the few occasions that it did not, it barely crossed the lane markers.

The steady-state handling test revealed that both vehicles in all load conditions had a positive and increasing understeer coefficient characteristic. The dual stretcher ambulance had similar understeer characteristics in turns to both left and right. The single stretcher ambulance had higher understeer in left turns than right, giving the driver the sense that the vehicle reacted quicker and better in right turns since less steer was required to complete the manoeuvre.

Both ambulances generally had a quicker response to the left in abrupt steer situations, with the exception of the single stretcher ambulance fully loaded, which responded faster to the right in low-speed situations.

In the spiral turn, the dual stretcher ambulance required a 20% increase in steer for right turns over left turns – a minor difference. The single stretcher ambulance required 50%-

70% more steer to execute the right turn. This could have a confusing effect on drivers not familiar with this characteristic. At speeds approaching 65 km/h in this manoeuvre, the tire noise, visible rear slide, and excessive chassis roll were such that it was concluded that the vehicle had reached its performance limit. This was usually between 0.6 g and 0.8 g.

In the obstacle avoidance manoeuvre, both vehicles showed excessive rear axle sliding near the exit of the manoeuvre. In all cases the vehicles recovered to complete the course with little attendant weaving or oscillation. In the case of the dual stretcher ambulance, higher sliding was predominantly detected in manoeuvres to the right, while the single stretcher ambulance showed a higher overall tendency to slide in both directions.

The computer simulation predicted progressive understeer in the steady-state constant radius test. The simulation does not allow for suspension bottoming or non-linearities in the suspension curves; therefore, it should be treated as supporting information only.

The handling test portion of this test program employed speeds up to 80 km/h and lateral accelerations to approximately 0.7 g on dry asphalt. In several instances it was noted that this loading caused the vehicle to reach its safe lateral response limits and any further increase would have caused spin-out. During the RCMP driving course, the speeds achieved were approximately 125 km/h (75 mph). Although the vehicle was able to negotiate the course, it must be remembered that the vehicle was operated by a very experienced test driver who had practised the individual manoeuvres. Even with the previous considerations, the vehicle still exhibited some response lag and sliding tendencies.

Both ambulances handle consistently and well on a dry high-friction surface. Low-friction surfaces, such as wet or icy roads, gravel roads, or combinations thereof, reduce the slide threshold considerably below the 0.6 g encountered in the tests. Operation at high speeds on low-friction surfaces, where there is the likelihood of achieving lateral accelerations in excess of 0.4 g, should be avoided.

Once the test driver had become accustomed to the vehicle, he was able to drive the vehicle close to its stability limits at high-speed and high lateral acceleration. It would be unrealistic to expect ambulance drivers to achieve this performance consistently without some specific training.

8 / RECOMMENDATIONS

It is recommended that the owners and operators of this particular ambulance chassis specify a heavier duty leaf spring retainer, or specify performance criteria for that component when ordering their vehicles. Specifications concerning engine stall during aggressive braking should also be incorporated in the OEM specification package. Also, conversion contractors should be made aware of chassis wheel interference problems that may occur at large roll angles. This should be in the conversion specifications.

It is recommended that ambulance drivers be made aware of the asymmetrical handling characteristics of these ambulance models, in steady state, transient, and braking modes. It is further recommended that drivers' training include a high performance driving course in the vehicle that they will be expected to operate. This should include demonstrations of the effect of biased loading, modes of instability during aggressive manoeuvres, and braking strategies.

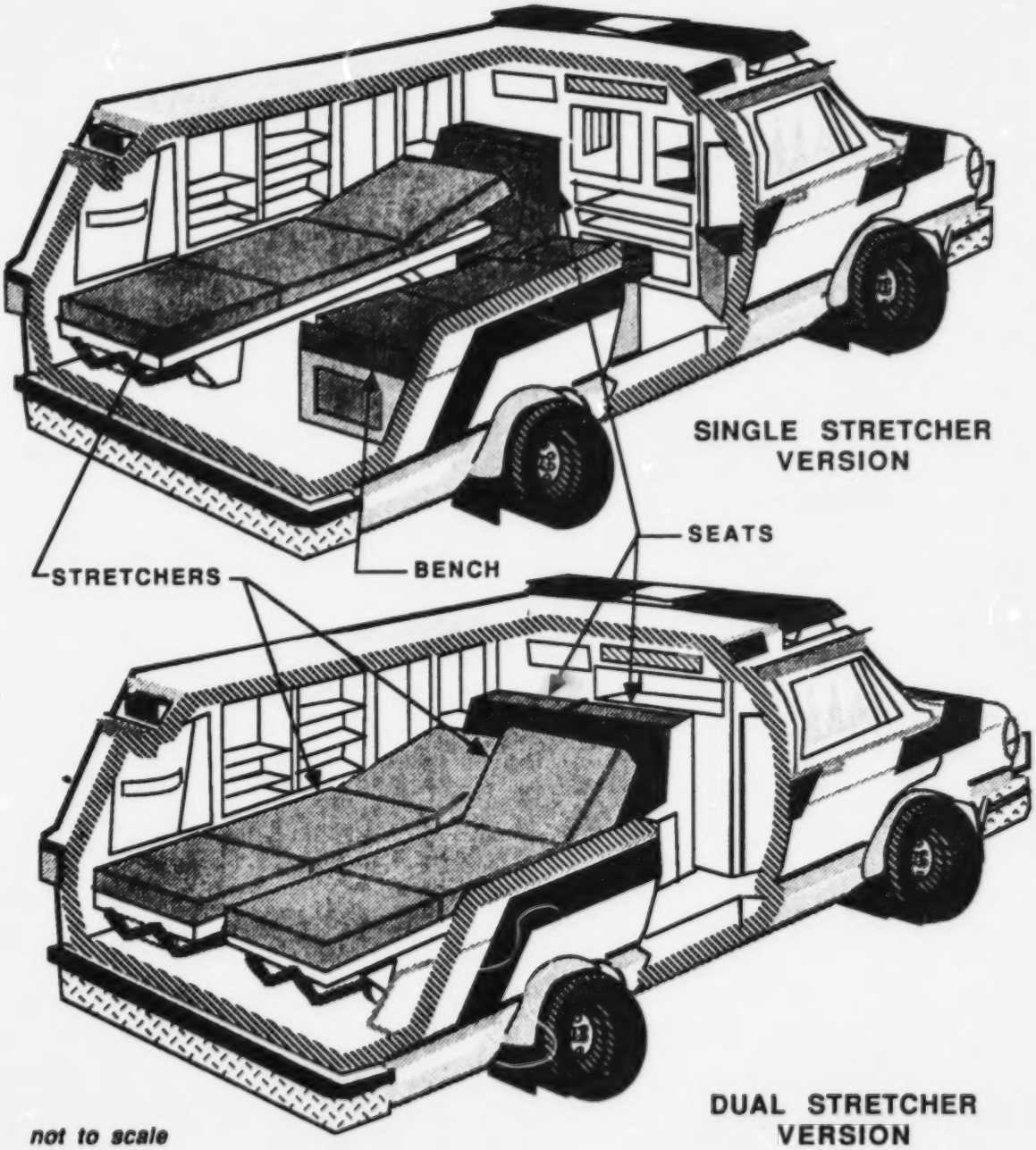
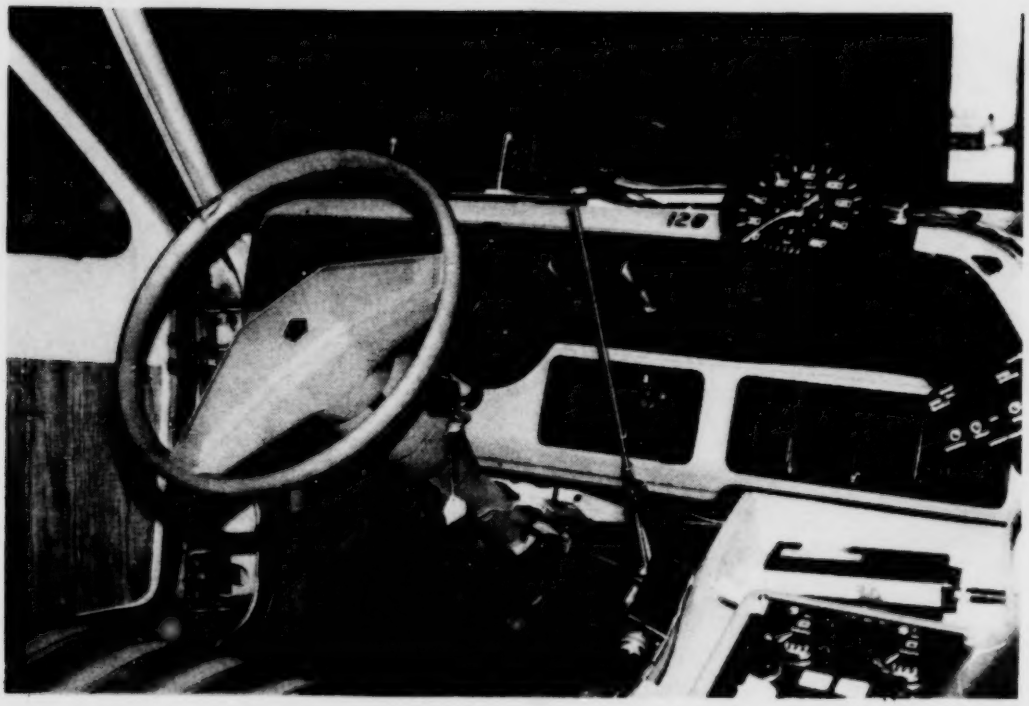
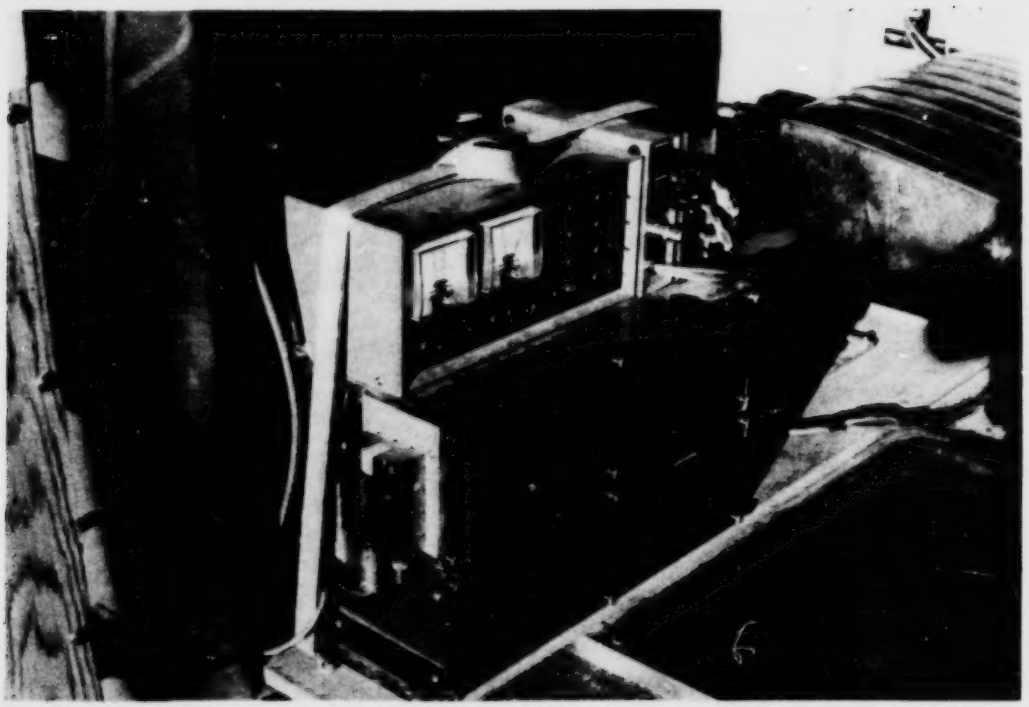


Figure 1/ Single and Dual Stretcher Ambulance – Cutaway Layout



(a) Driver's Station



(b) Payload Compartment

Figure 2/ On Board Instrumentation

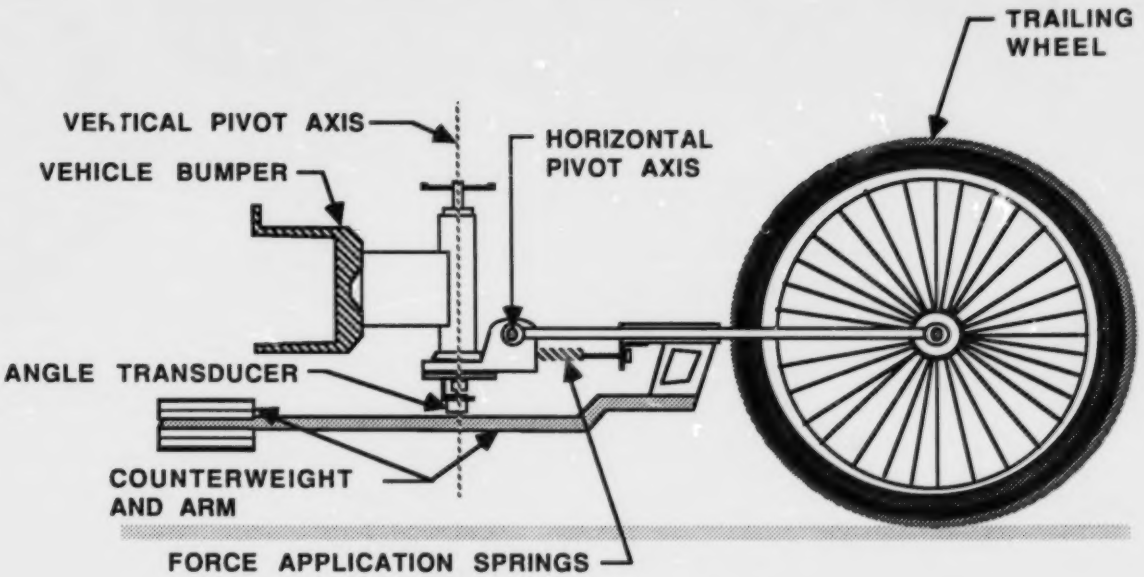


Figure 3/ Counter-Balanced Trailing Wheel

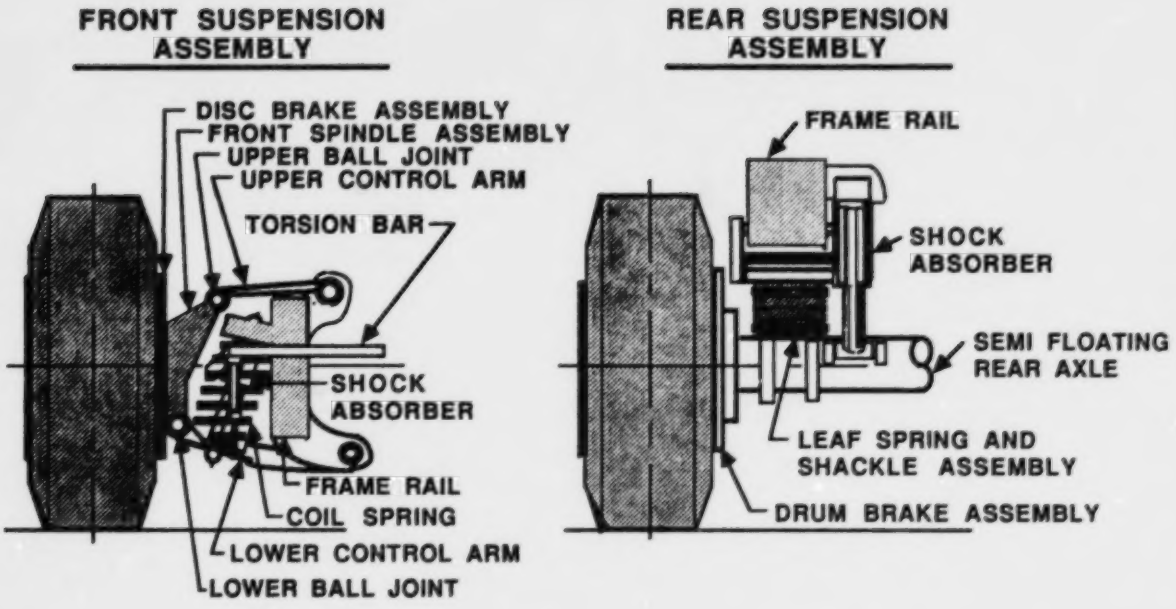


Figure 4/ Suspension Systems

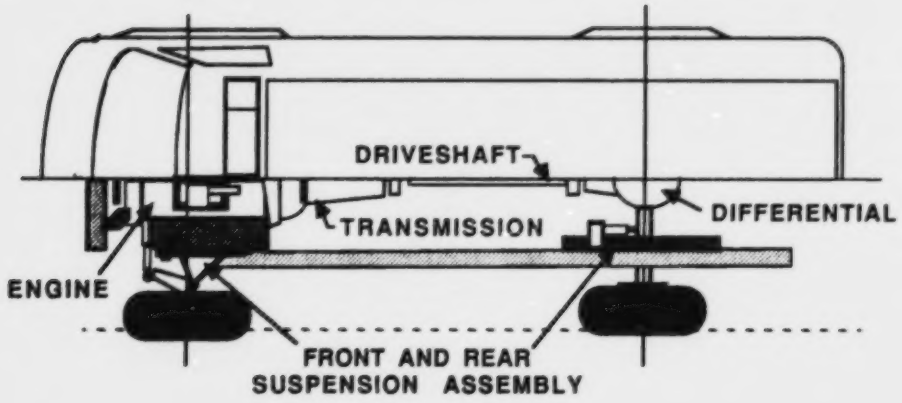
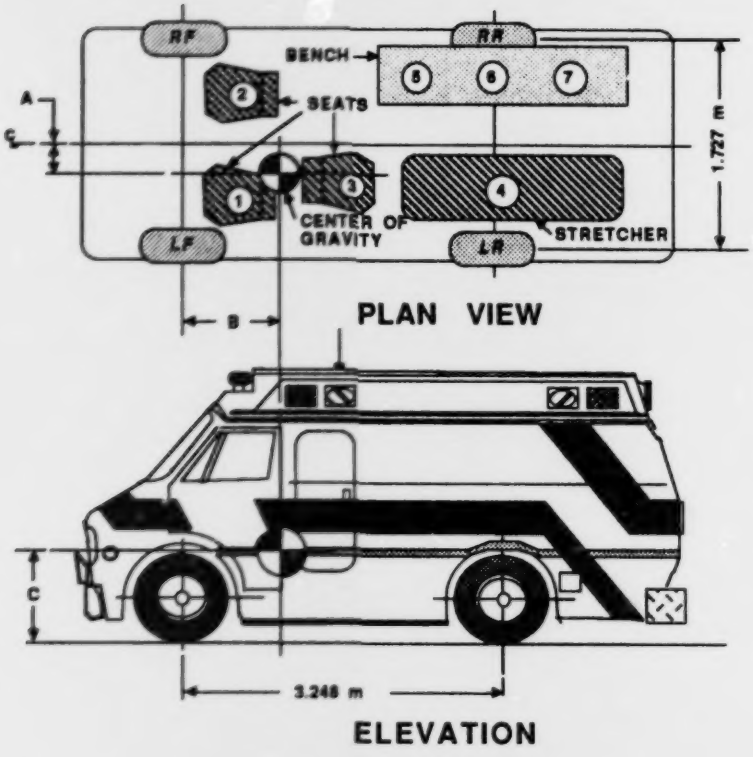


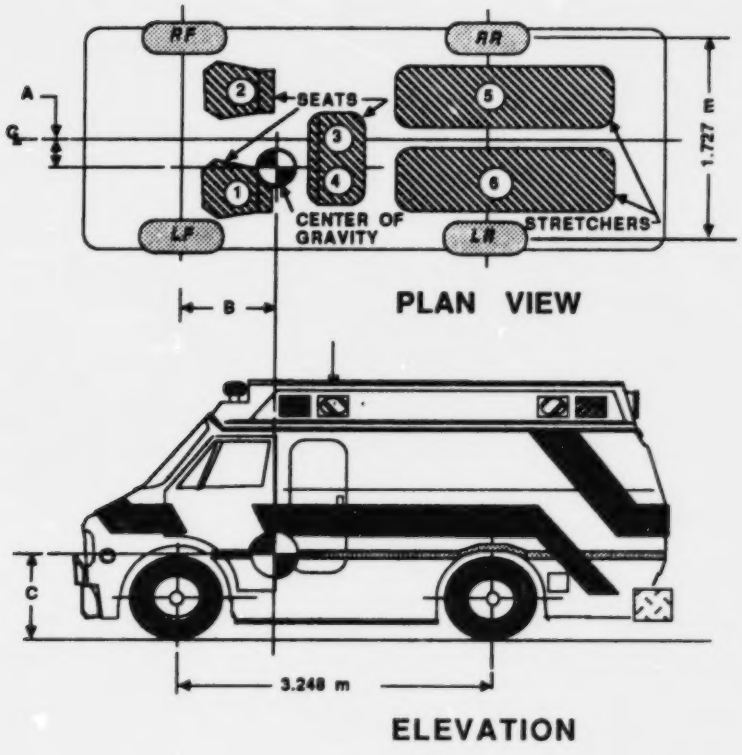
Figure 5/ Power Train Layout



Load and Balance Data – All Test Load Cases
Occupant Weight: 70 kg - Full Fuel Load

LOAD CASE	SEATS/STRETCHER OCCUPIED (POSITION NO.)							WHEEL LOADS (kg)				CENTER OF GRAVITY COORDINATES (m)		
	1	2	3	4	5	6	7	RF	LF	RR	LR	A	B	C
# 1	X	X						706	769	828	902	.037	1.759	0.858
# 2	X			X		X		693	752	887	963	.035	1.824	0.849
# 3	X	X		X		X		723	737	927	943	.078	1.824	0.867
# 4	X	X	X	X	X	X	X	754	726	1041	1004	-.018	1.843	0.869

Figure 6/ Single Stretcher Ambulance



Load and Balance Data – All Test Load Cases

Occupant Weight: 70 kg - Full Fuel Load

LOAD CASE	SEATS/STRETCHER OCCUPIED (POSITION NO.)						WHEEL LOADS (kg)				CENTER OF GRAVITY COORDINATES (m)		
	1	2	3	4	5	6	RF	LF	RR	LR	A	B	C
# 1	X	X					699	796	841	959	.056	1.774	.828
# 2	X				X*	X	674	781	884	1024	.064	1.843	.855
# 3	X			X	X	X	687	783	926	1057	.057	1.868	.819
# 4	X	X	X	X	X	X	752	823	970	1062	.039	1.830	.839

* Denotes seated on stretcher

Figure 7/ Dual Stretcher Ambulance

Figure 8/ Ambulance on Tilt Table

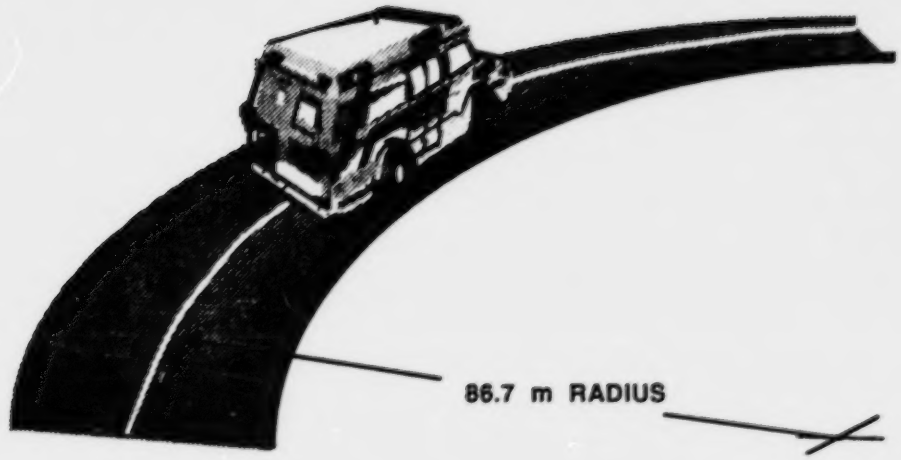


Figure 9/ Constant Radius Circle, Left and Right – Progressive Speeds

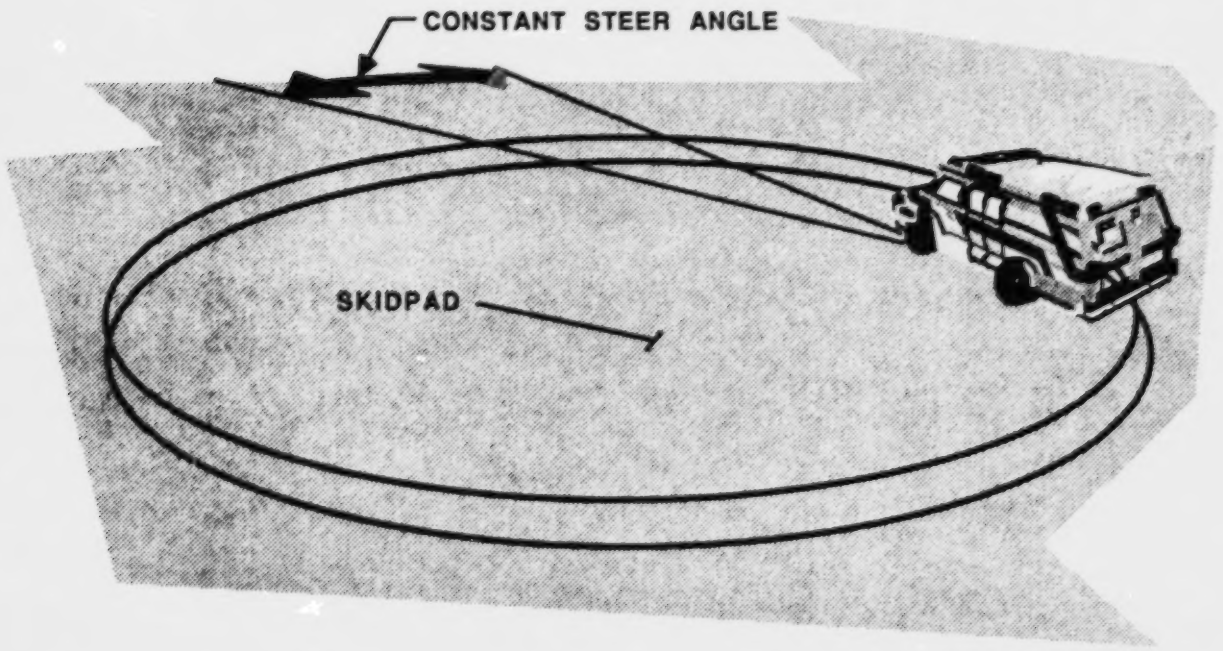


Figure 10/ Constant Steer Angle Test, Left and Right – Progressive Speeds

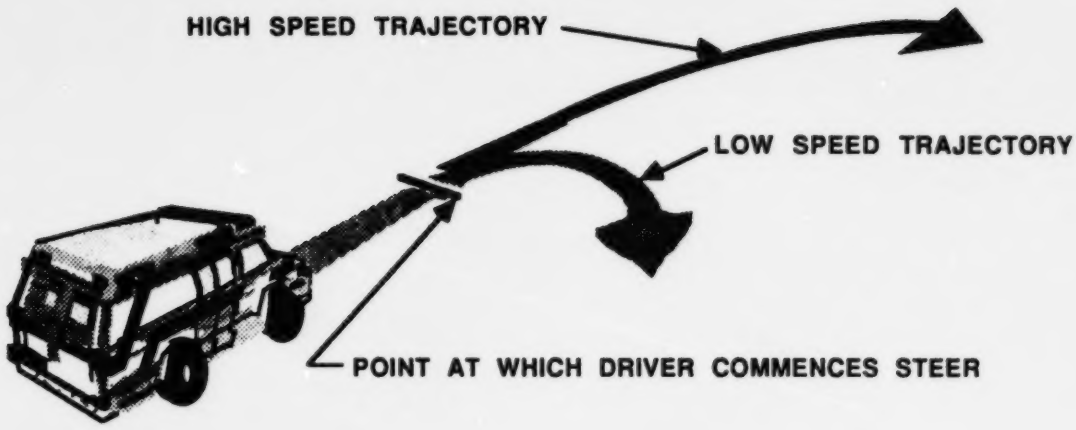


Figure 11/ J-Turn Manoeuvre, Left and Right – High and Low Speed

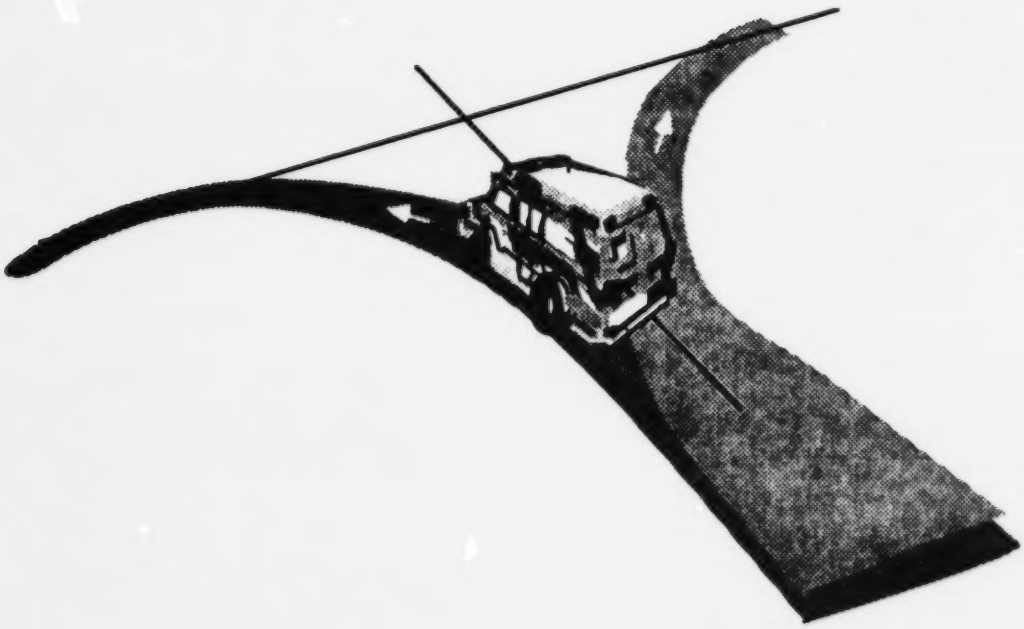


Figure 12/ Spiral 90° Turn, Left and Right – Progressive Speeds, Straight Path to 36.5 m Radius

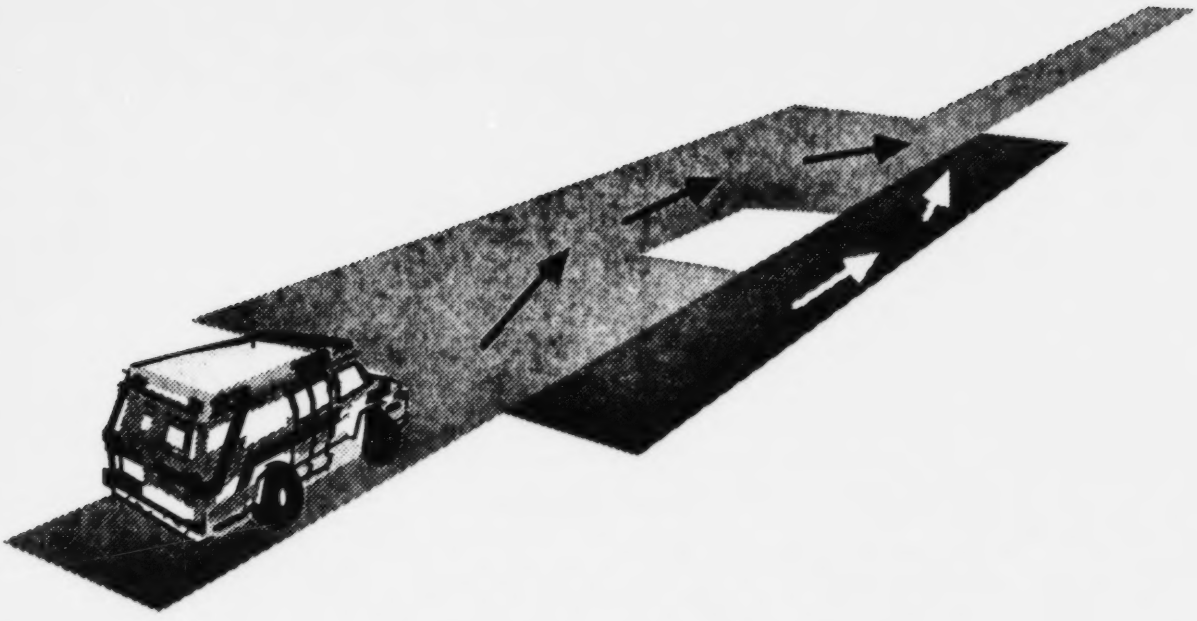


Figure 13/ Obstacle Avoidance Manoeuvre, Left and Right – Progressive Speeds, 18.3-9.2-18.3 m Gate Sizes – 3.05 m Lane Width

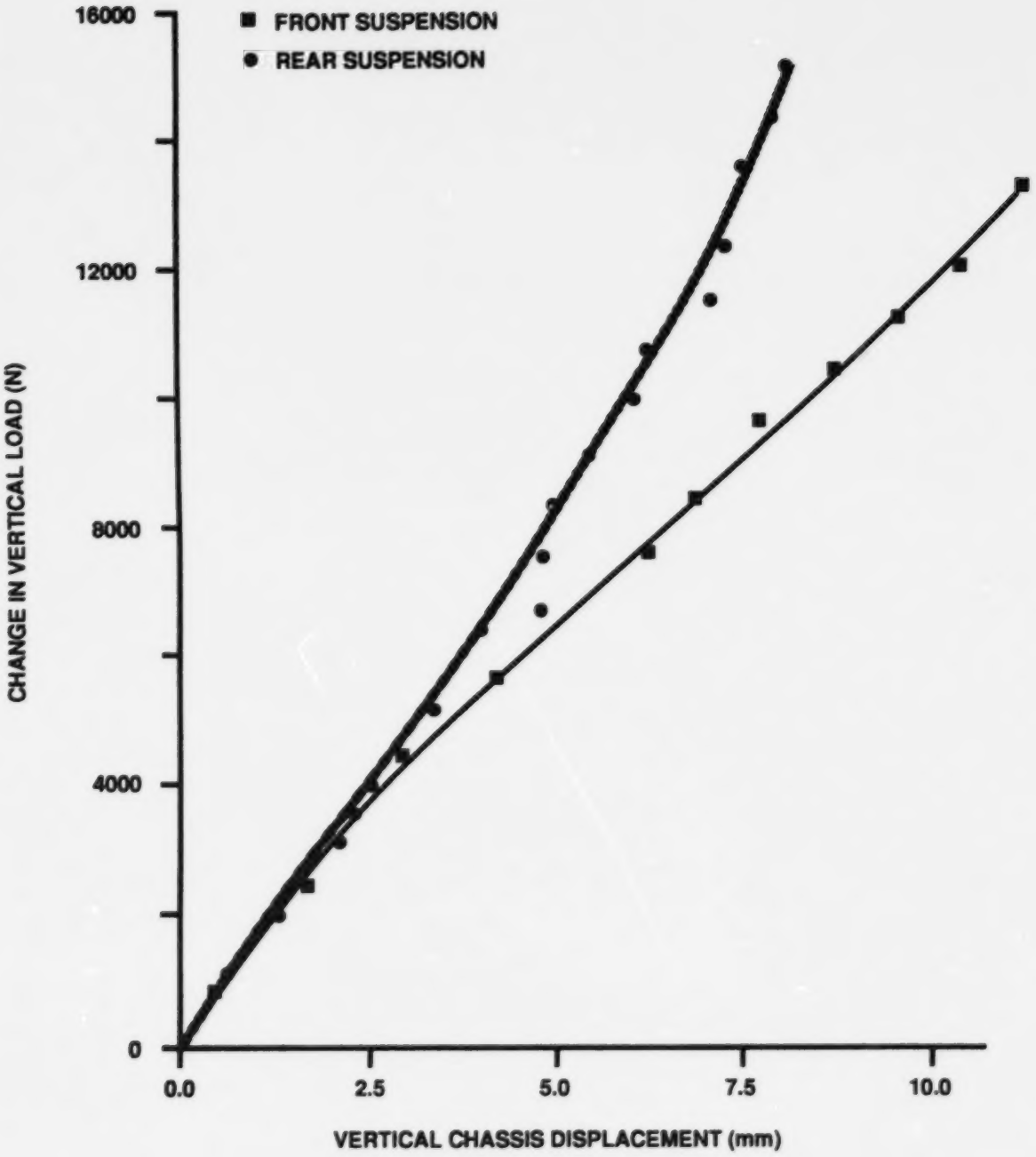


Figure 14/ Load Displacement, Front and Rear Suspensions – Single and Dual Stretcher Ambulances

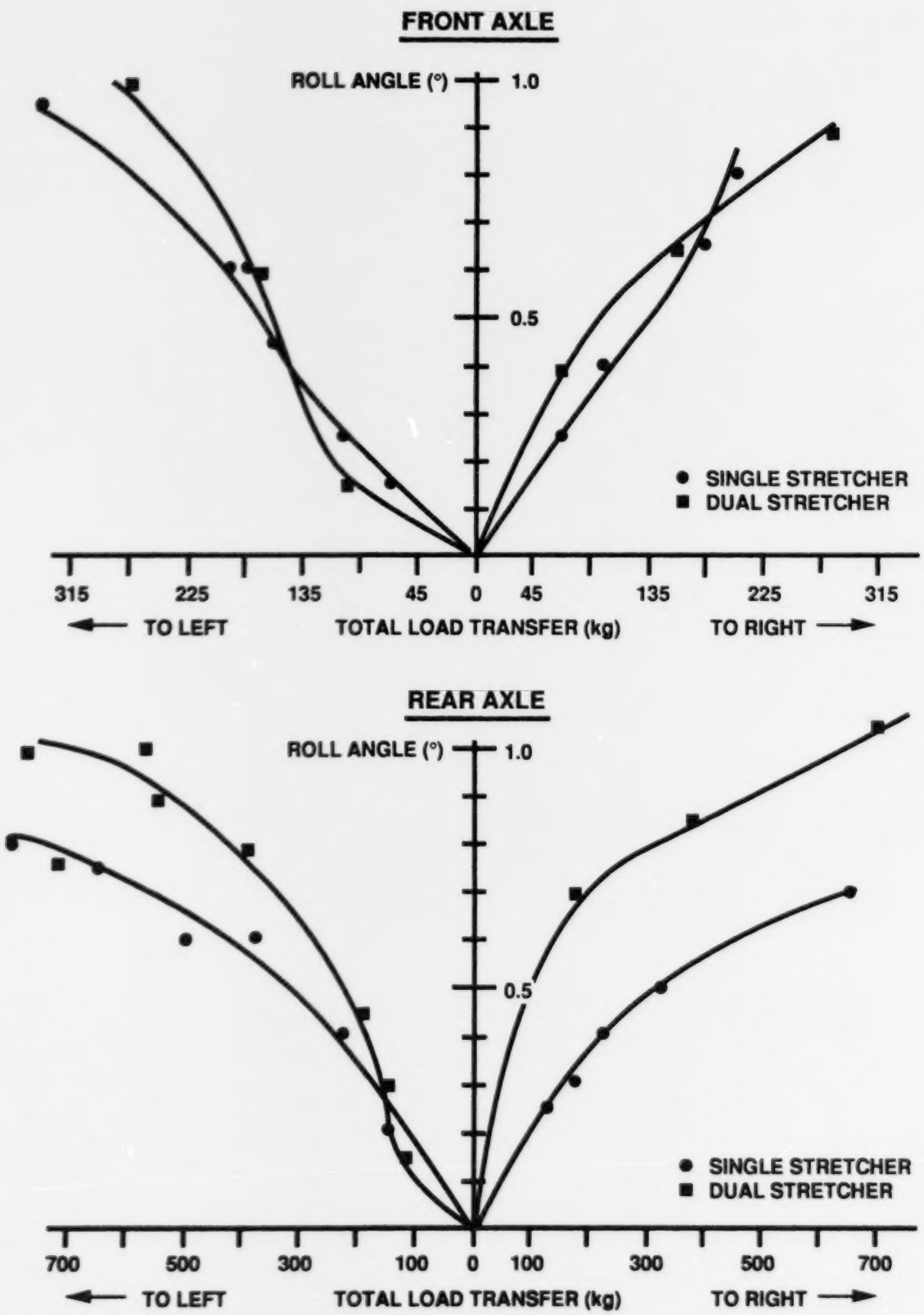


Figure 15/ Roll Angle vs Load Transfer (low roll angles) – Single and Dual Stretcher Ambulances

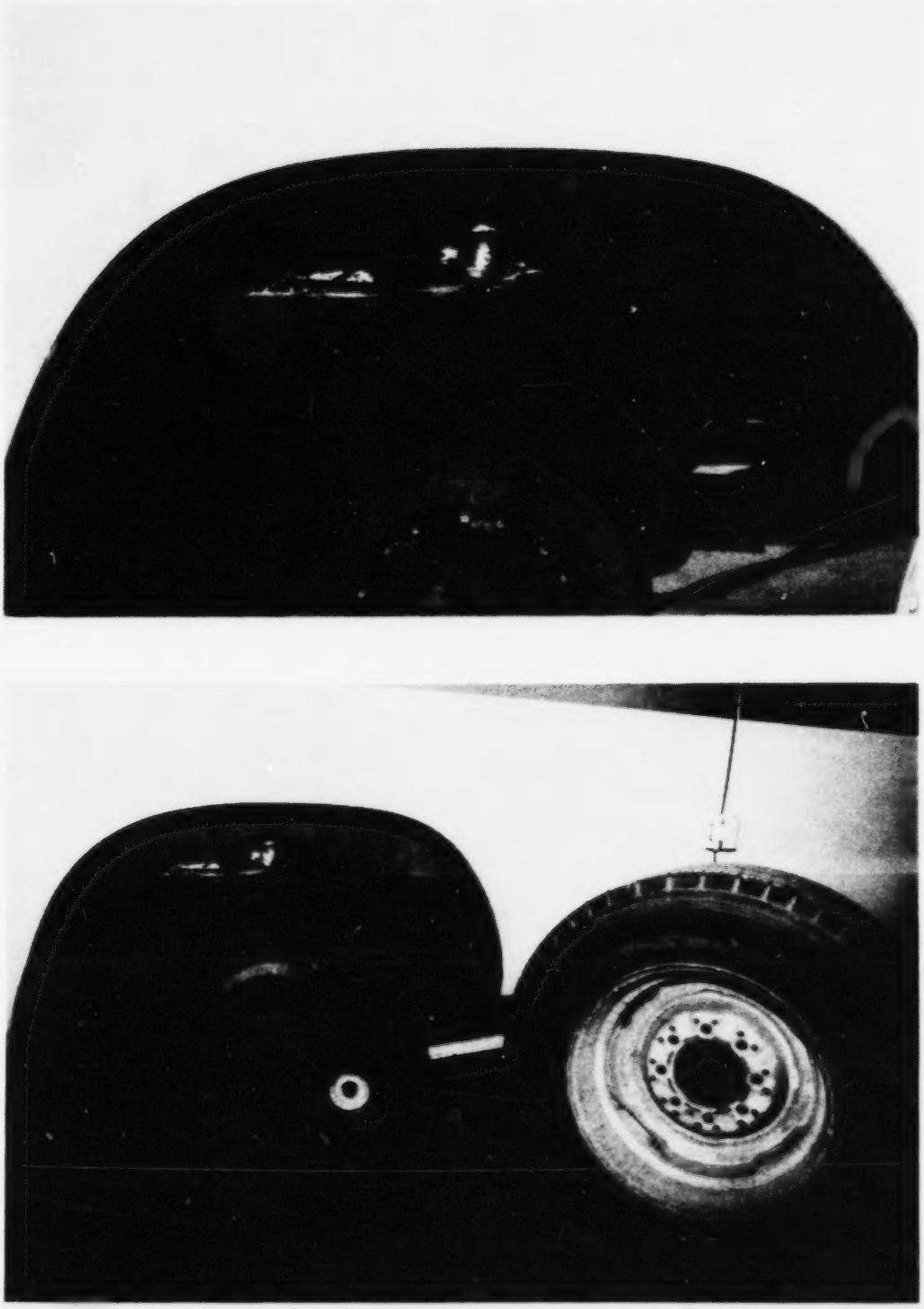


**Figure 16/ Sidewall Scuffing on Chassis,
Dual Stretcher Ambulance – Right Rear Fenderwall**

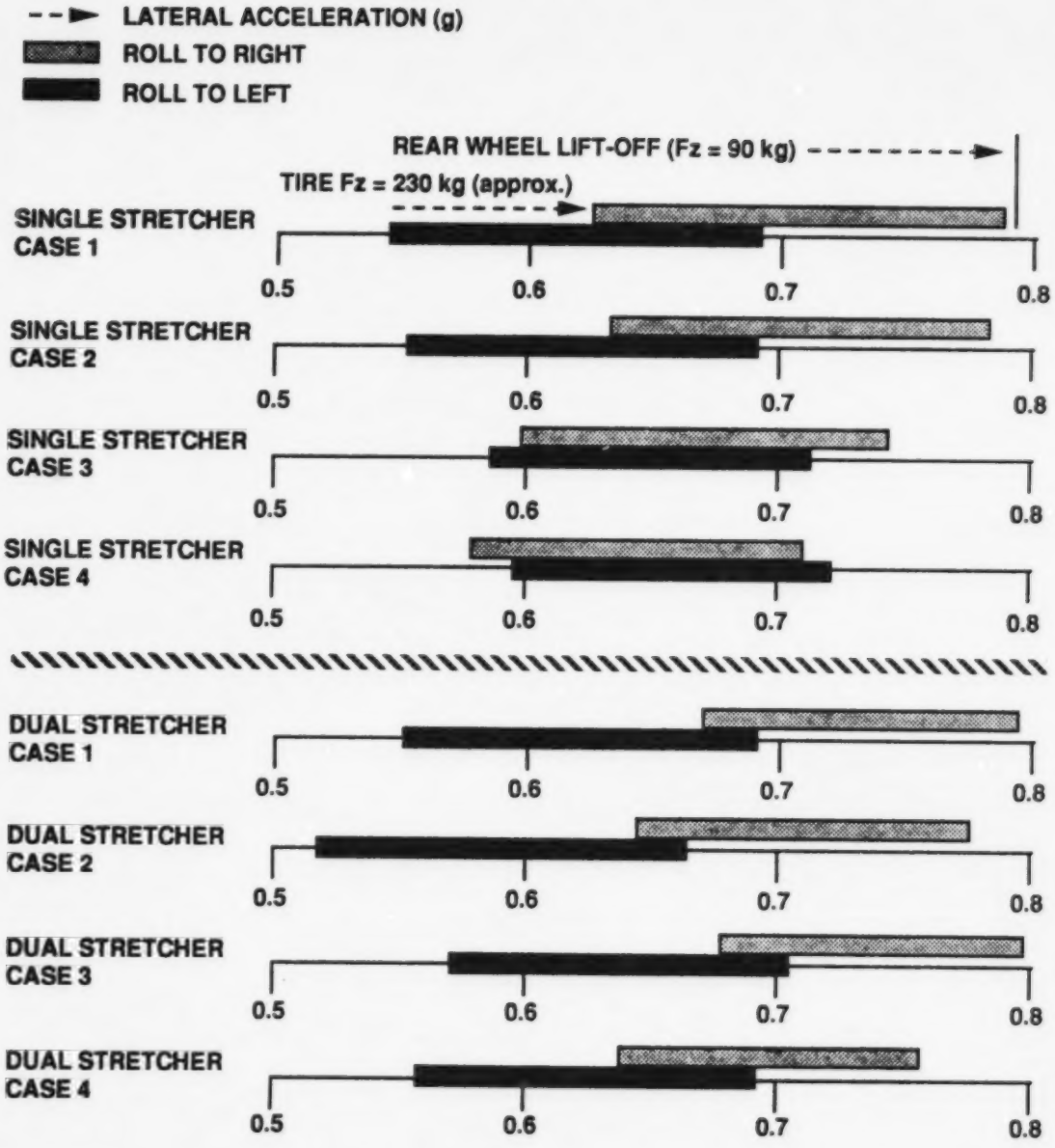


Figure 17/ Loss of Tire Performance Point (Fz = 230 kg approx.) and Approximate Wheel Lift-off Point at Corresponding Lateral Accelerations, Based on Tilt Table Test Data

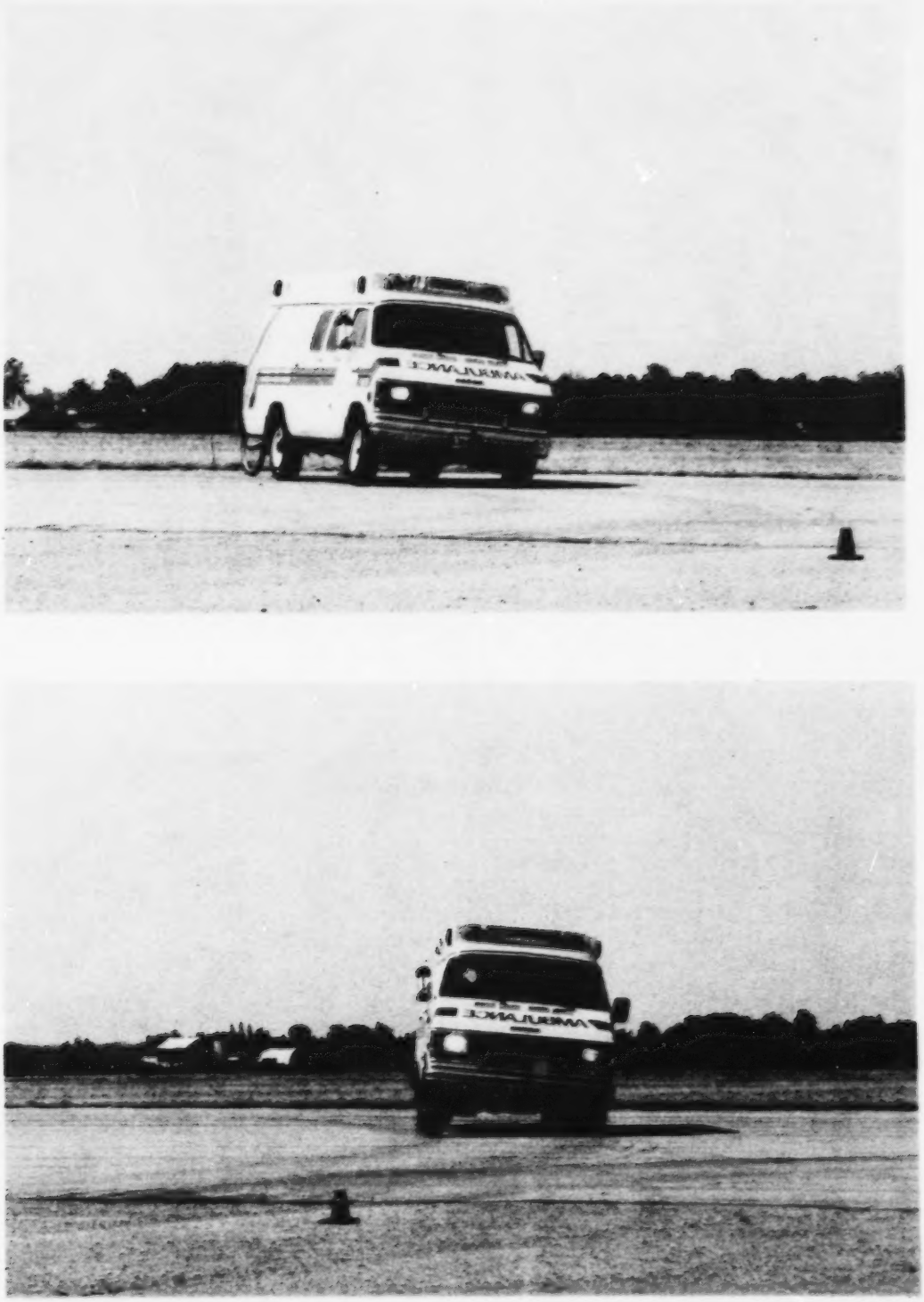


Figure 18/ Chassis Experiencing High Dynamic Sideloading

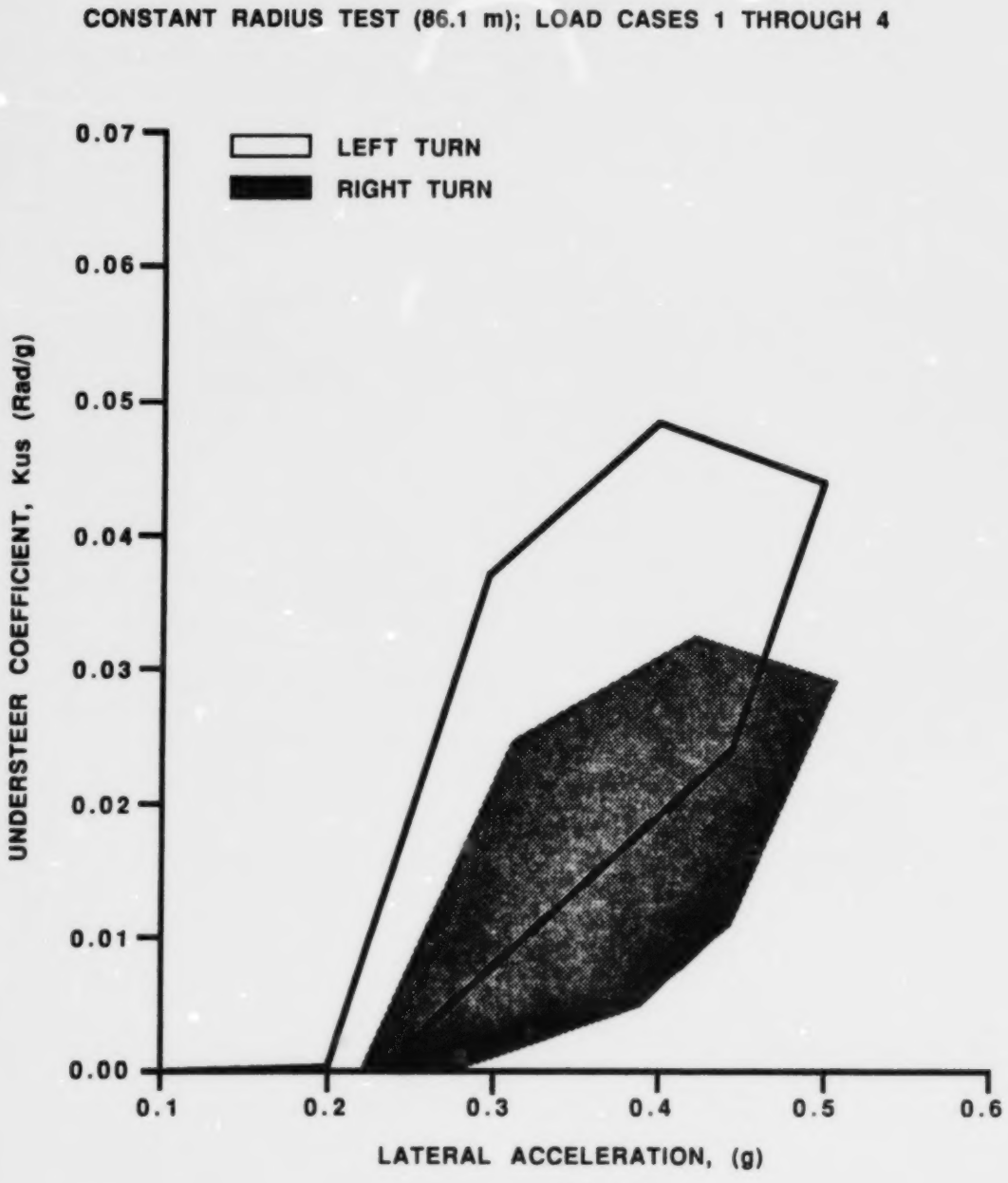


Figure 19/ Coefficient of Understeer vs Lateral Acceleration for Single Stretcher Ambulance

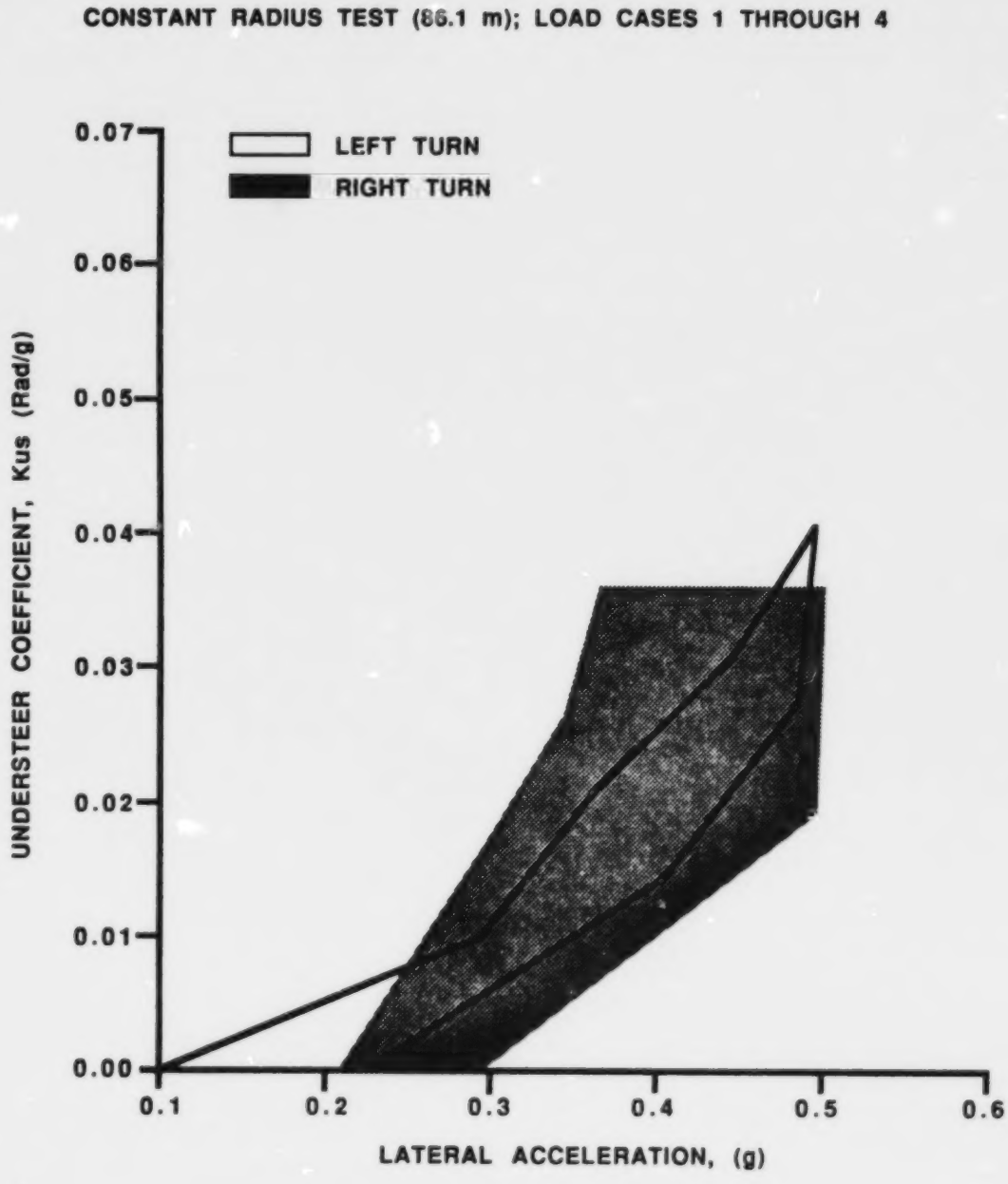


Figure 20/ Coefficient of Understeer vs Lateral Acceleration for Dual Stretcher Ambulance

DIFFERENCE IN SLIP ANGLE vs LATERAL ACCELERATION FOR SINGLE AND DUAL STRETCHER AMBULANCES, LEFT AND RIGHT TURNS – ALL LOAD CASES

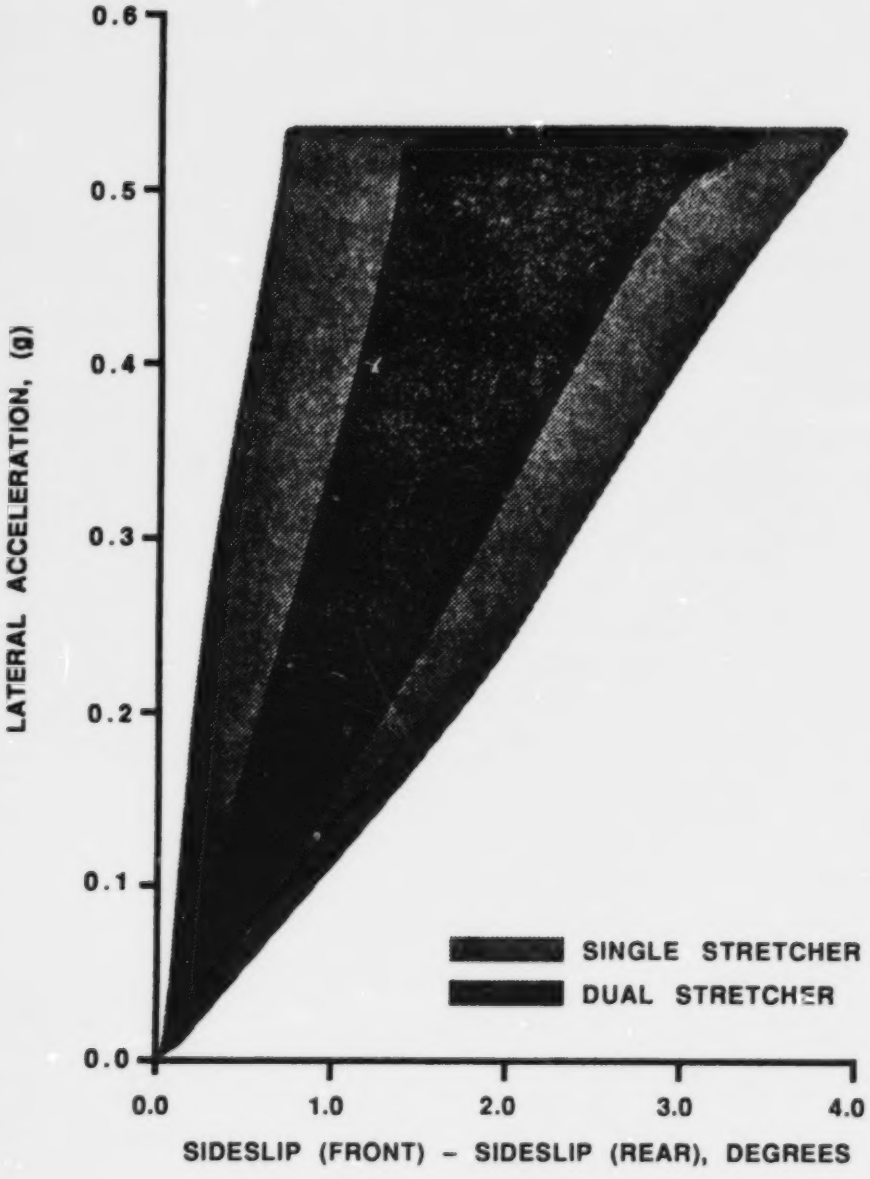


Figure 21/ Handling Curves Overall Performance Envelopes

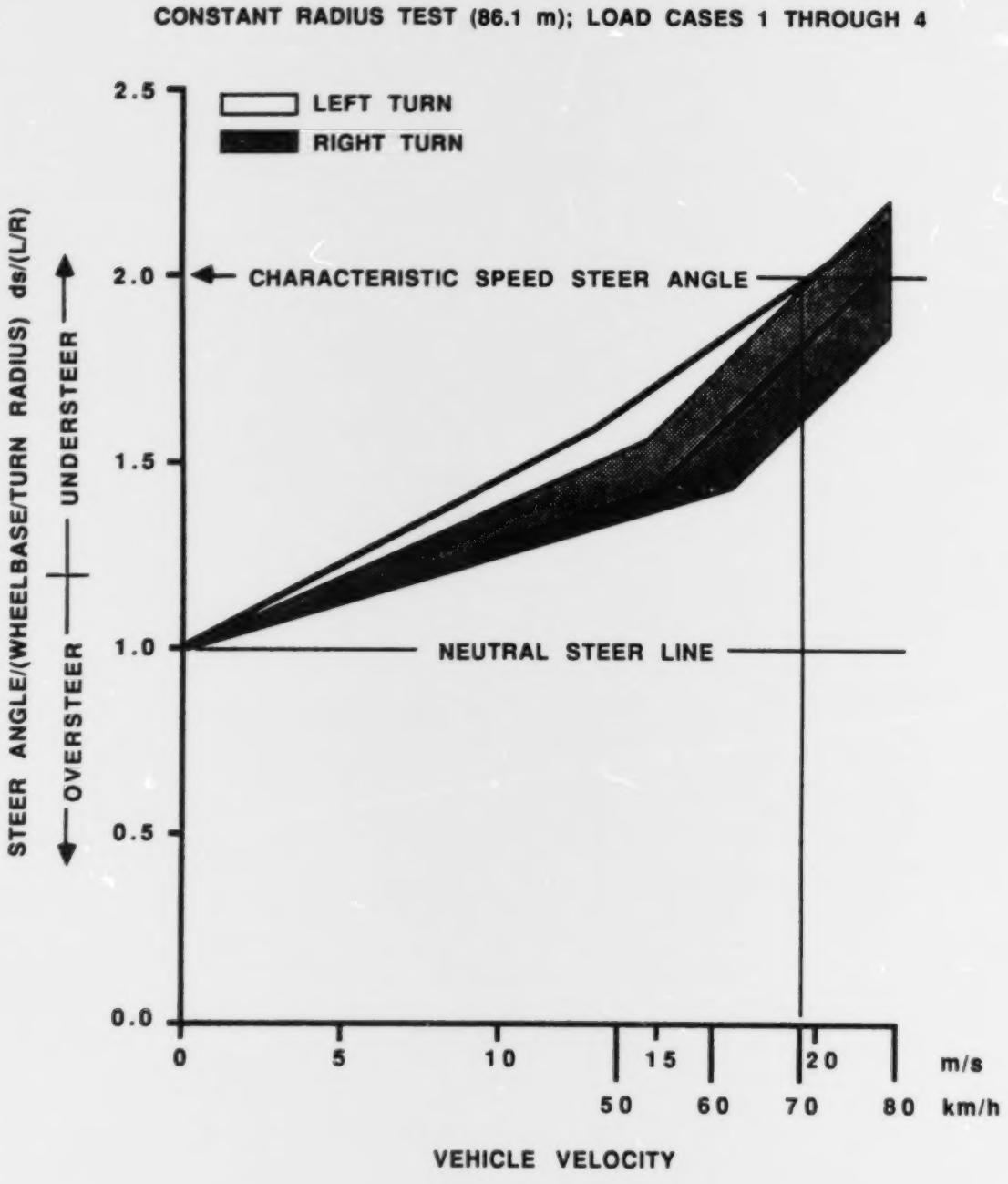


Figure 22/ Steer Angle vs Speed Curve for Dual Stretcher Ambulance

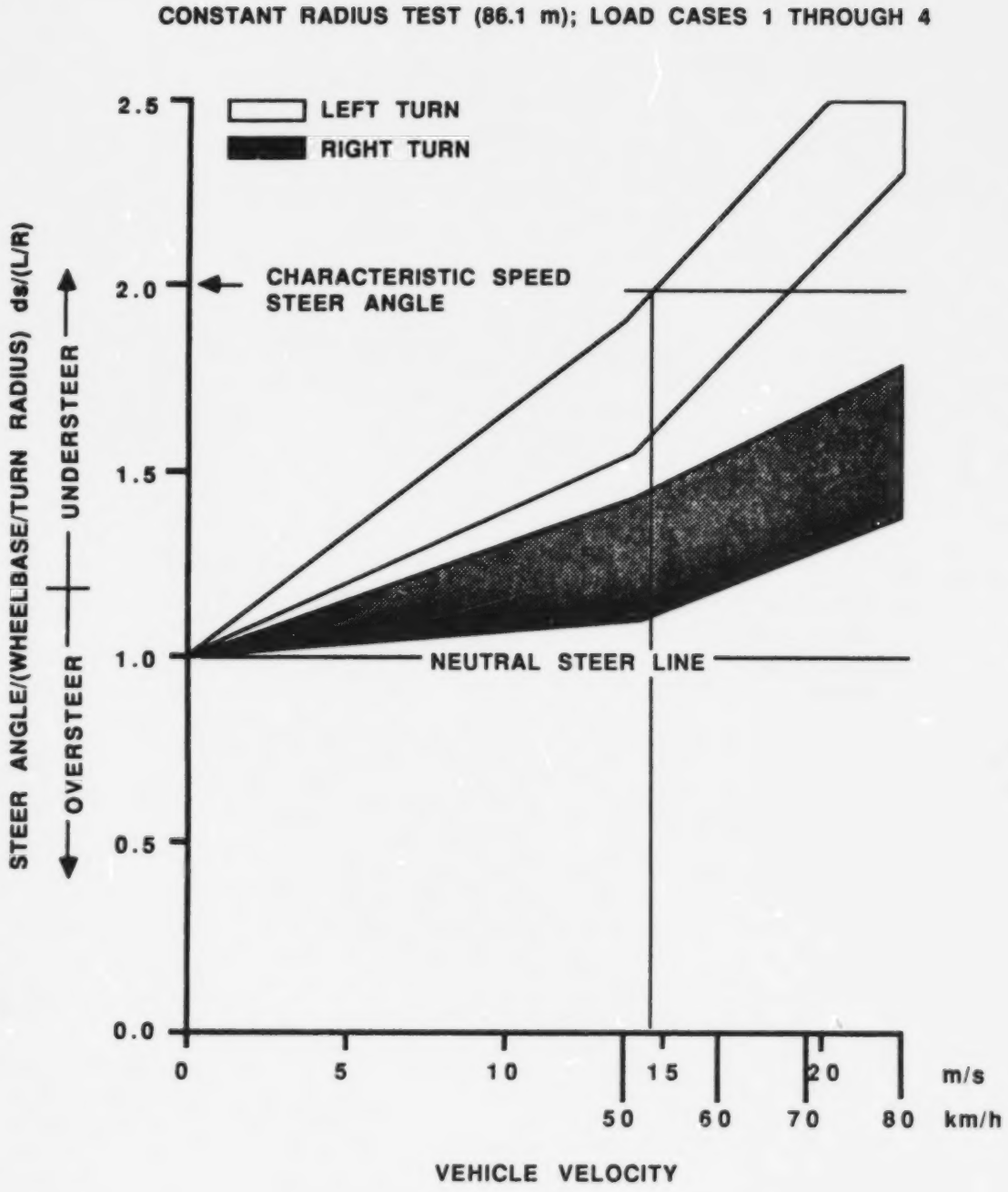


Figure 23/ Steer Angle vs Speed Curve for Single Stretcher Ambulance

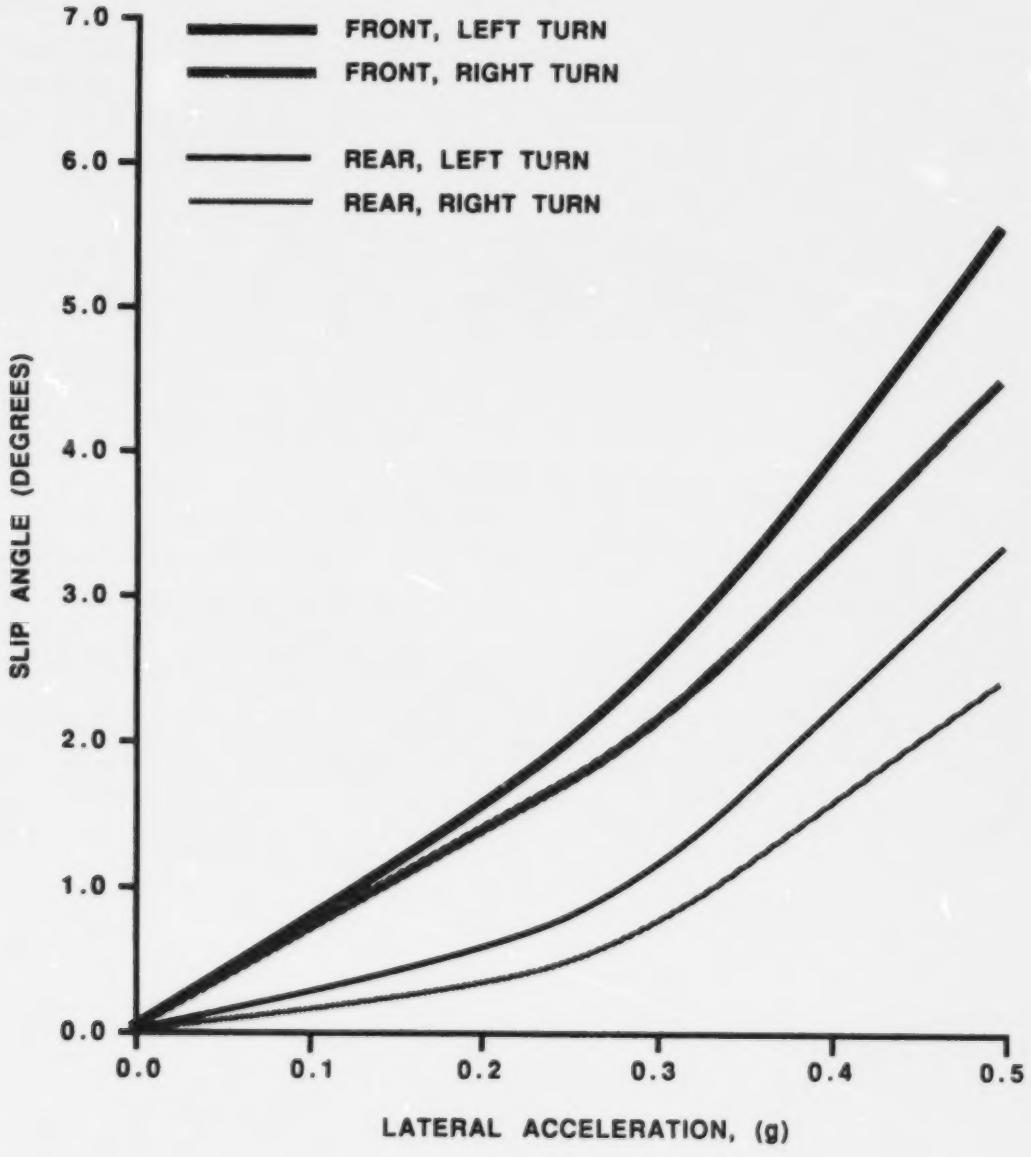


Figure 24/ Average Slip Angle vs Lateral Acceleration, Dual Stretcher – All Load Cases

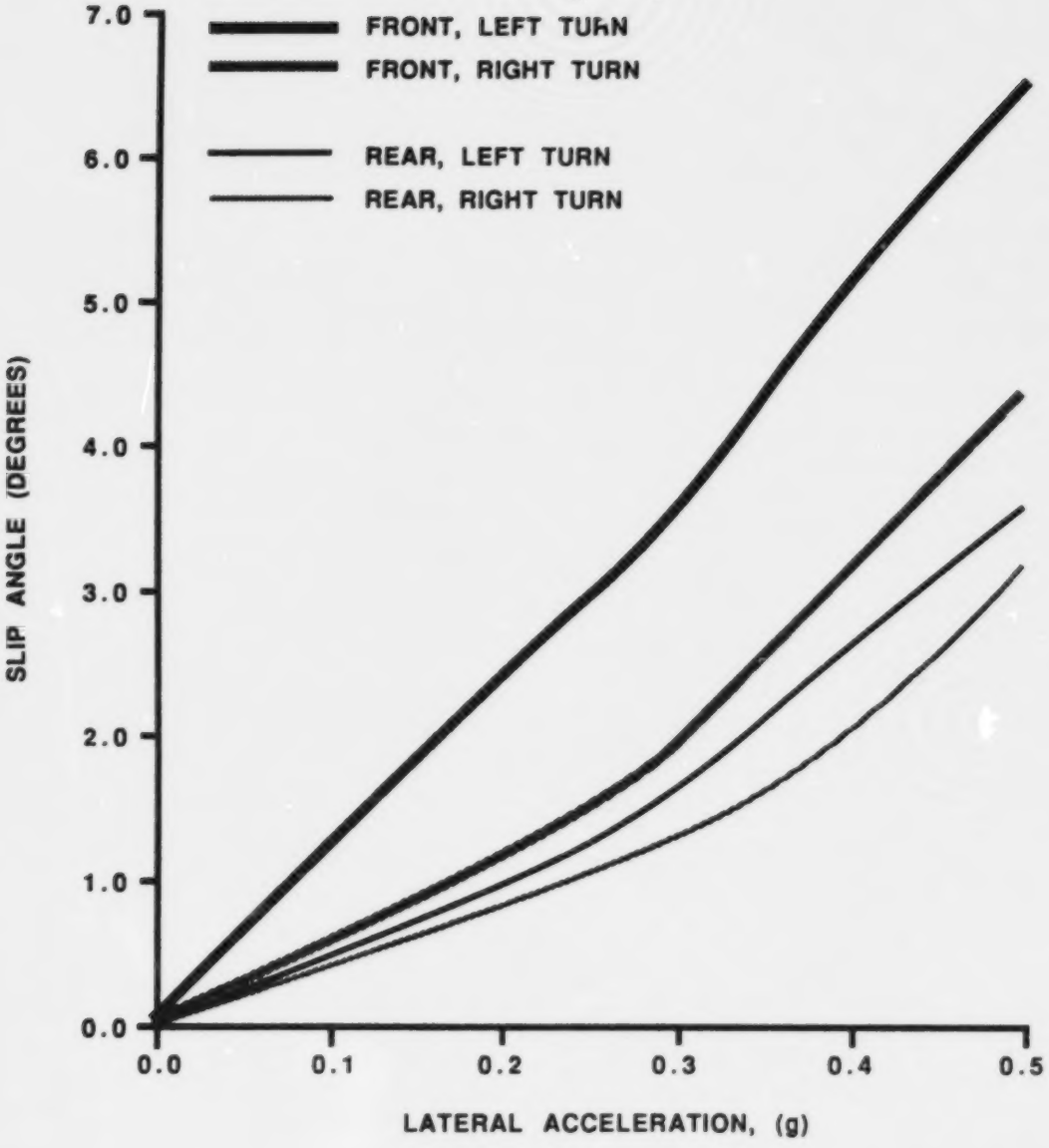


Figure 25/ Average Slip Angle vs Lateral Acceleration, Single Stretcher – All Load Cases

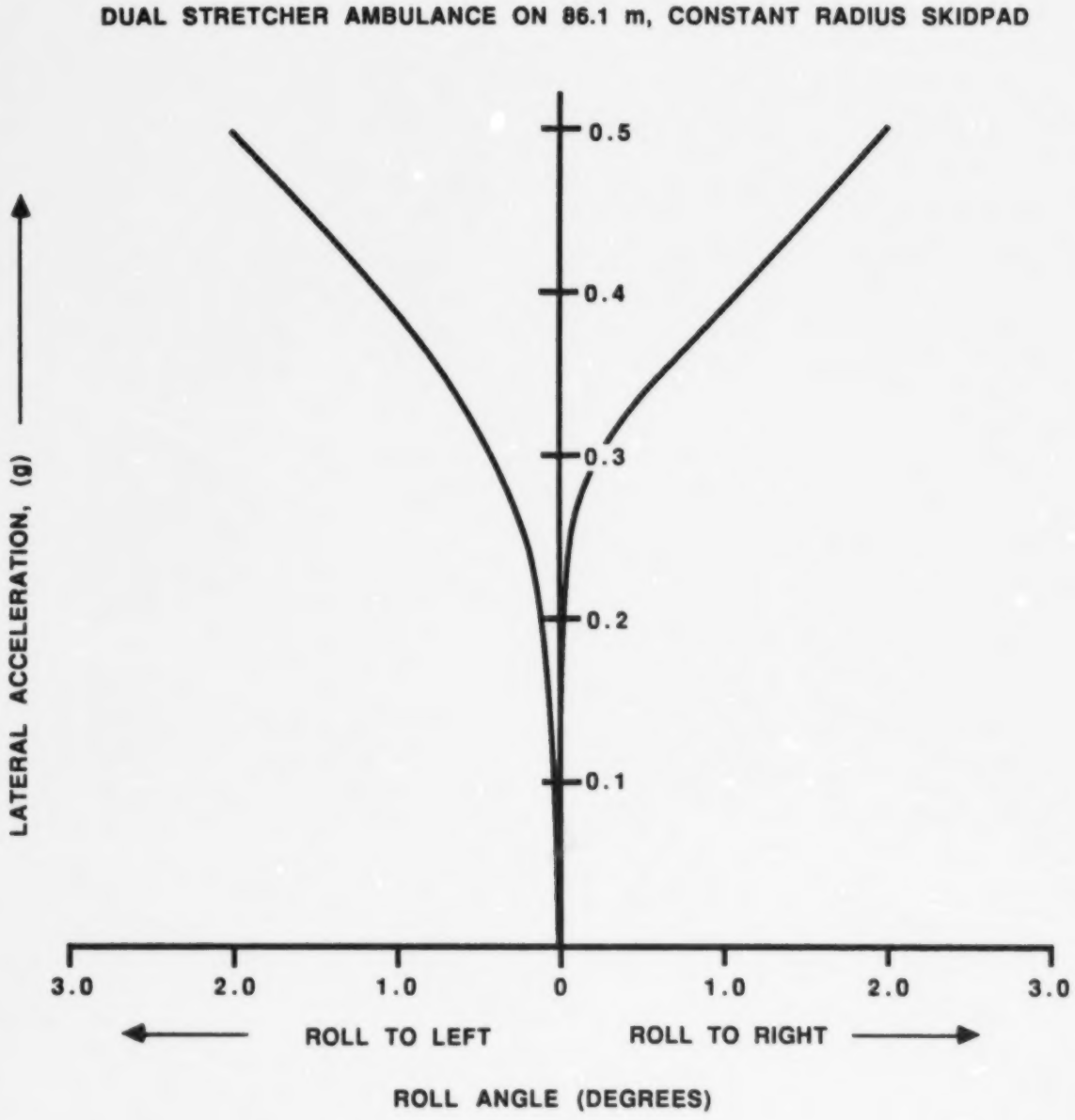


Figure 26/ Roll Angle vs Lateral Acceleration

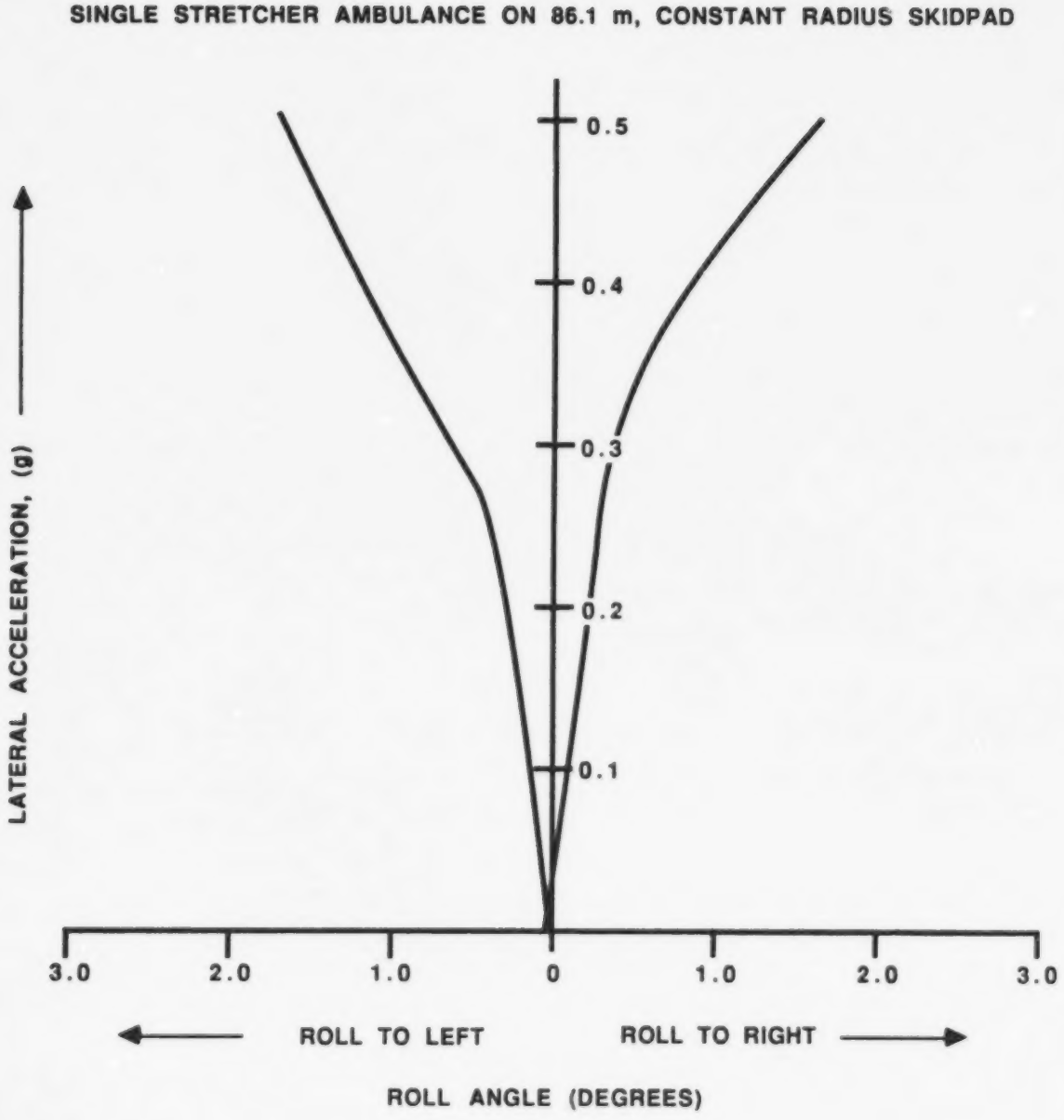


Figure 27/ Roll Angle vs Lateral Acceleration

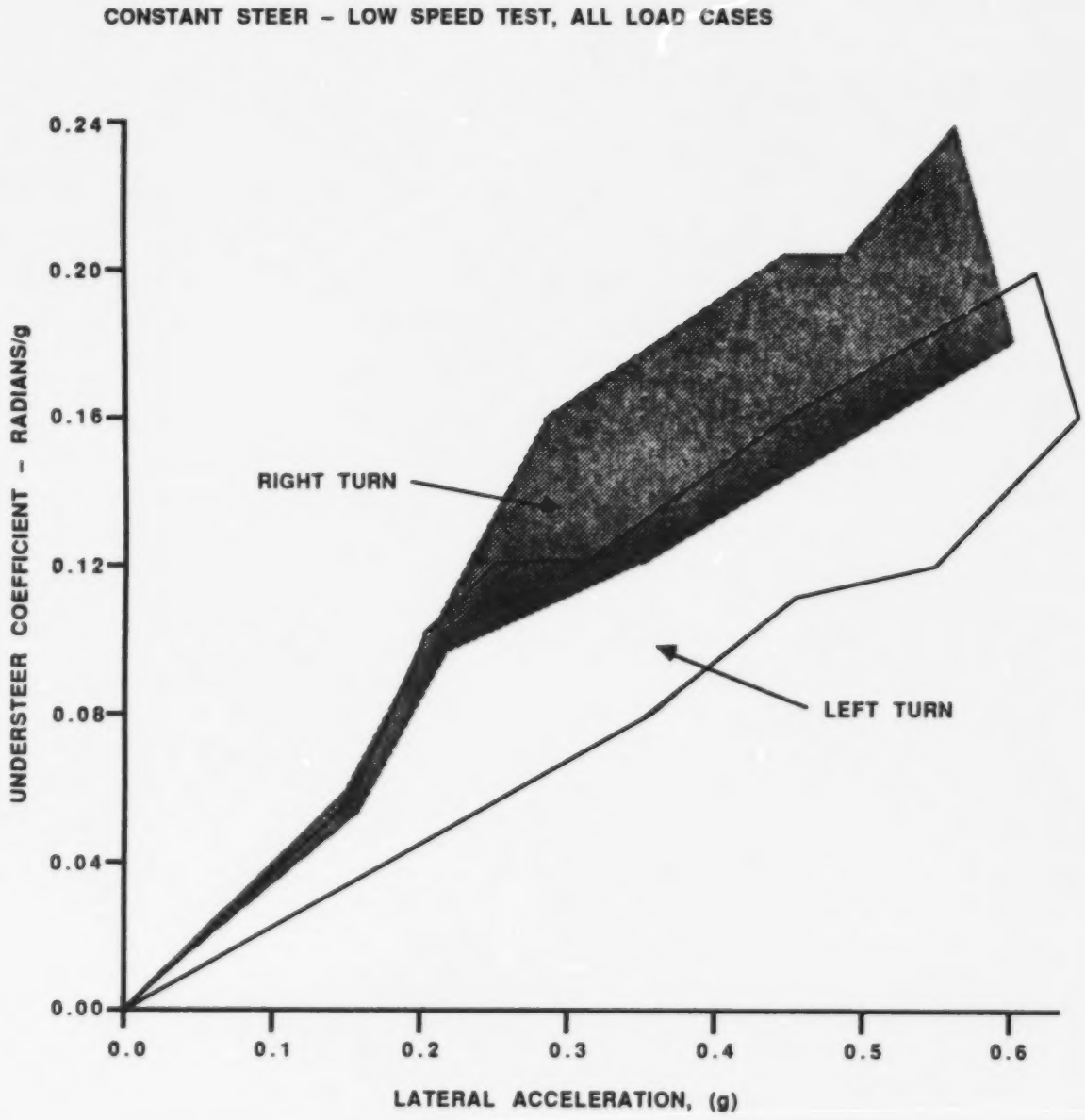


Figure 28/ Understeer Coefficient for Dual Stretcher Ambulance in Left and Right Turns

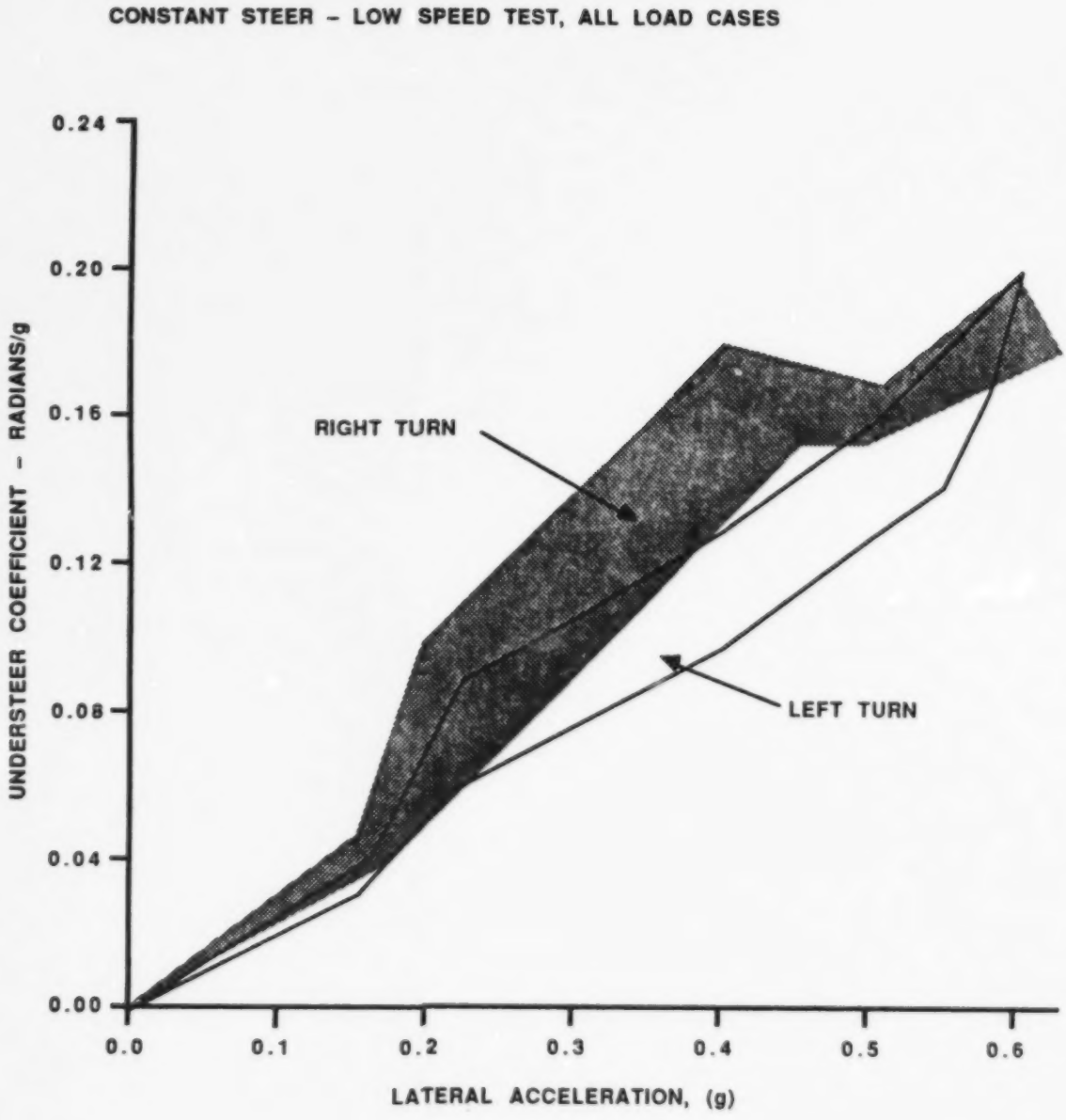


Figure 29/ Understeer Coefficient for Single Stretcher Ambulance in Left and Right Turns

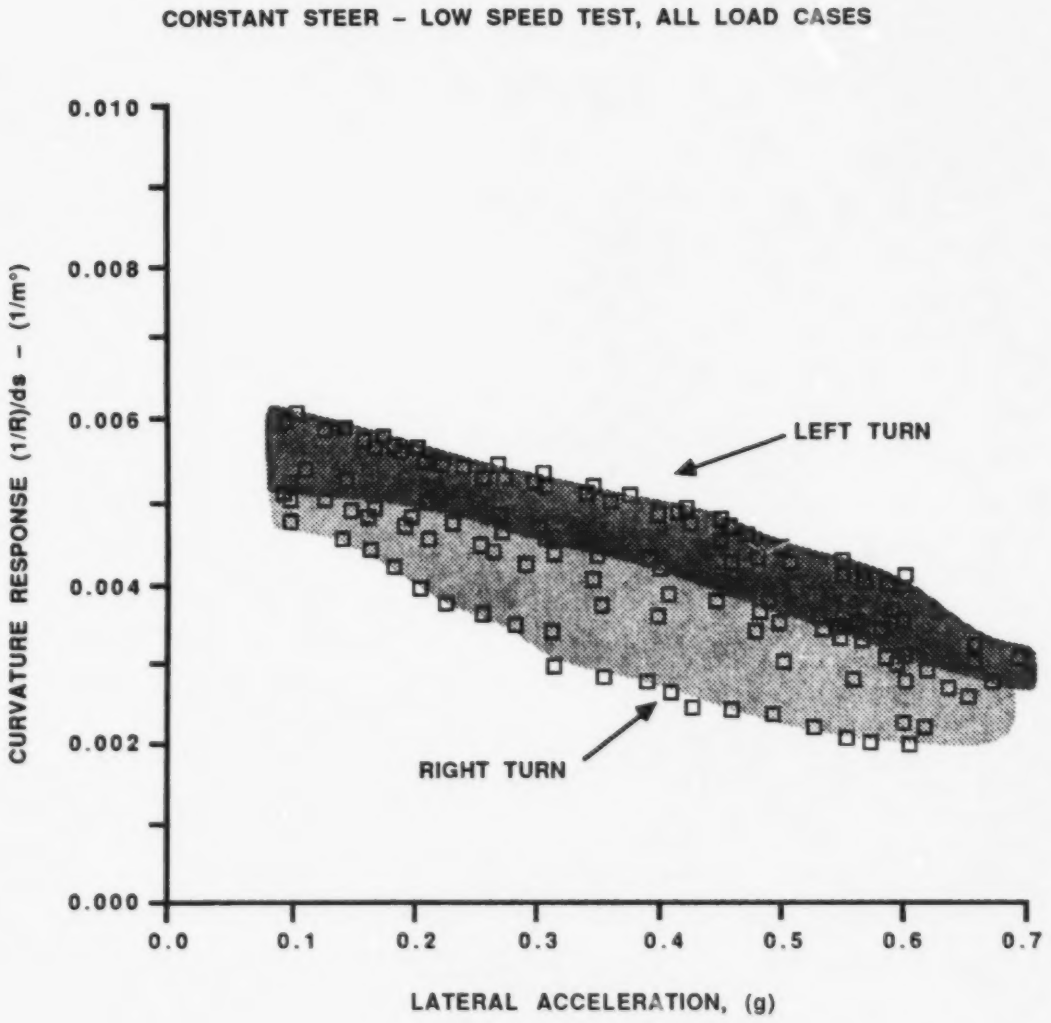


Figure 30/ Curvature Response Gain for Dual Stretcher Ambulance in Left and Right Turns

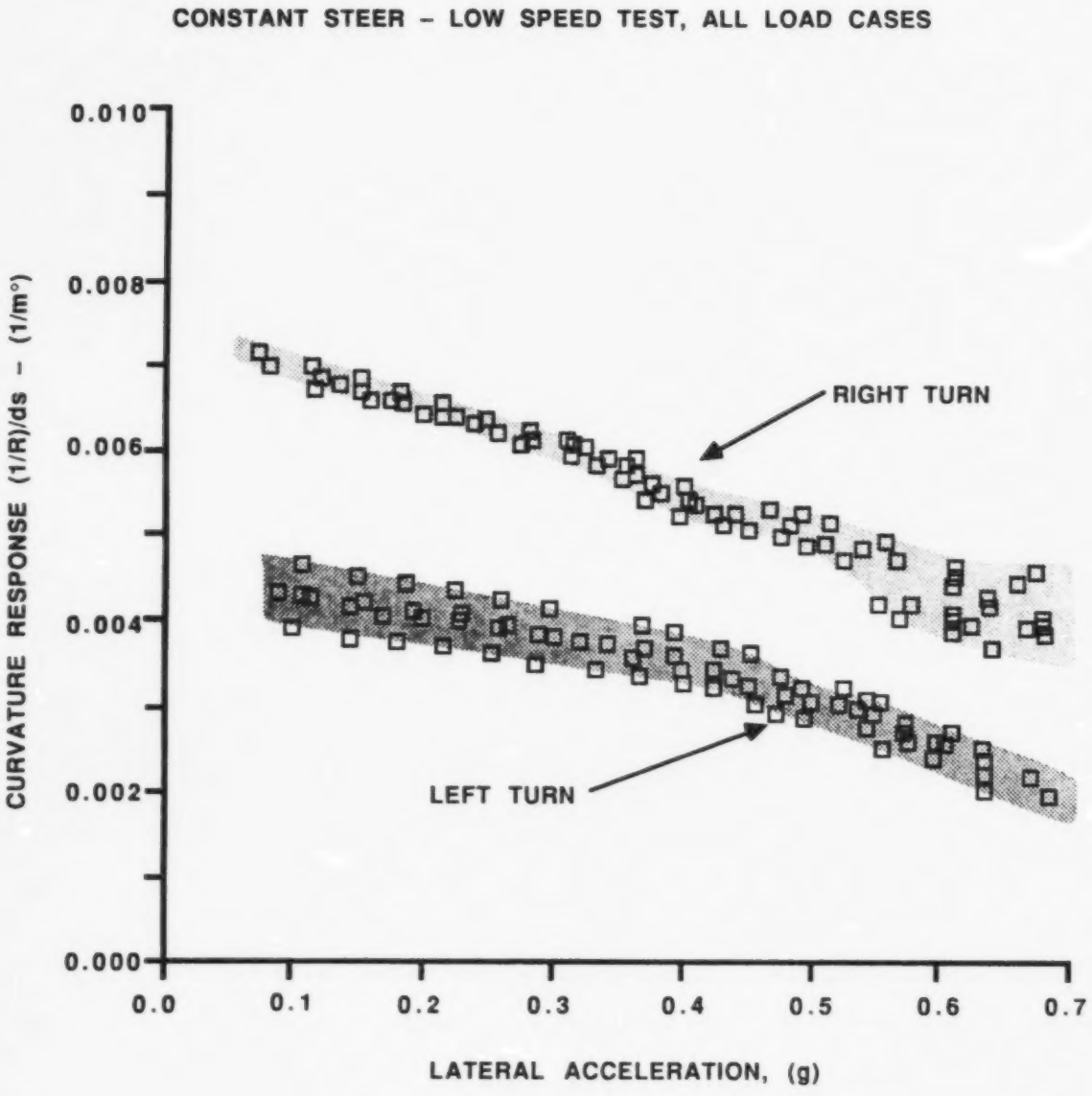


Figure 31/ Curvature Response Gain for Single Stretcher Ambulance in Left and Right Turns

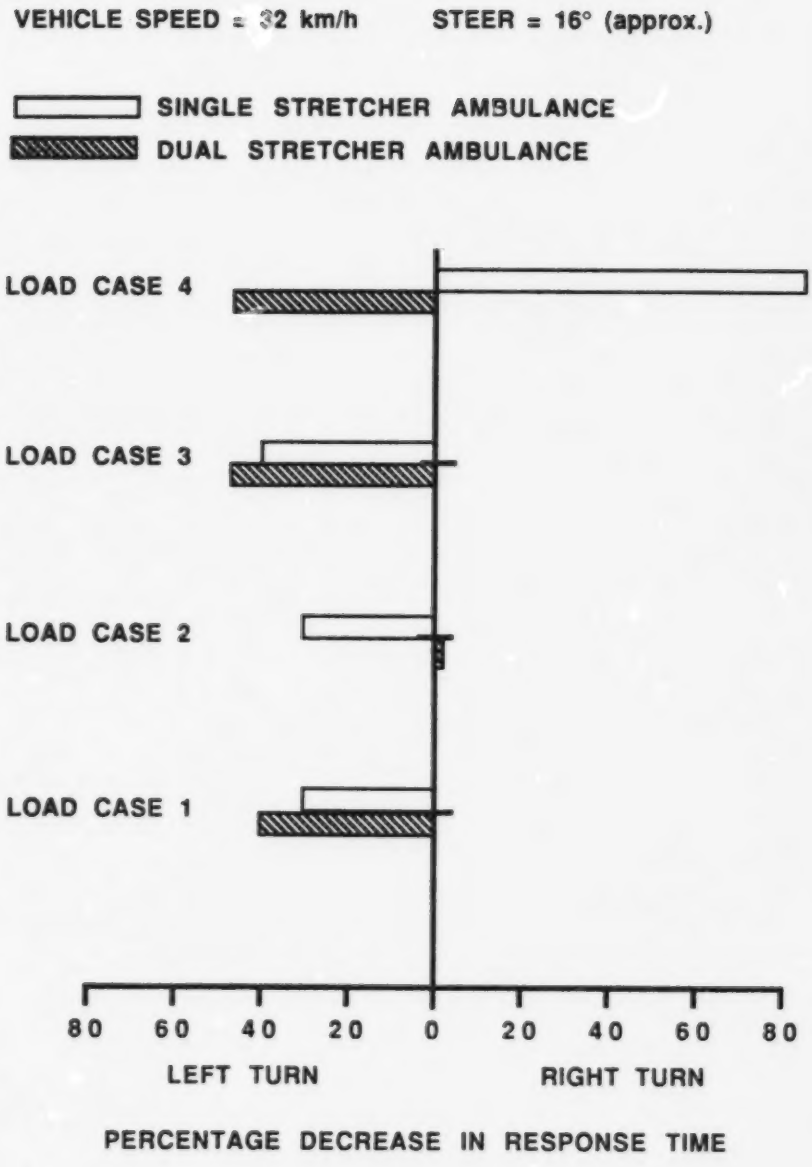


Figure 32/ Directional Response Comparison for Low Speed J-Turn

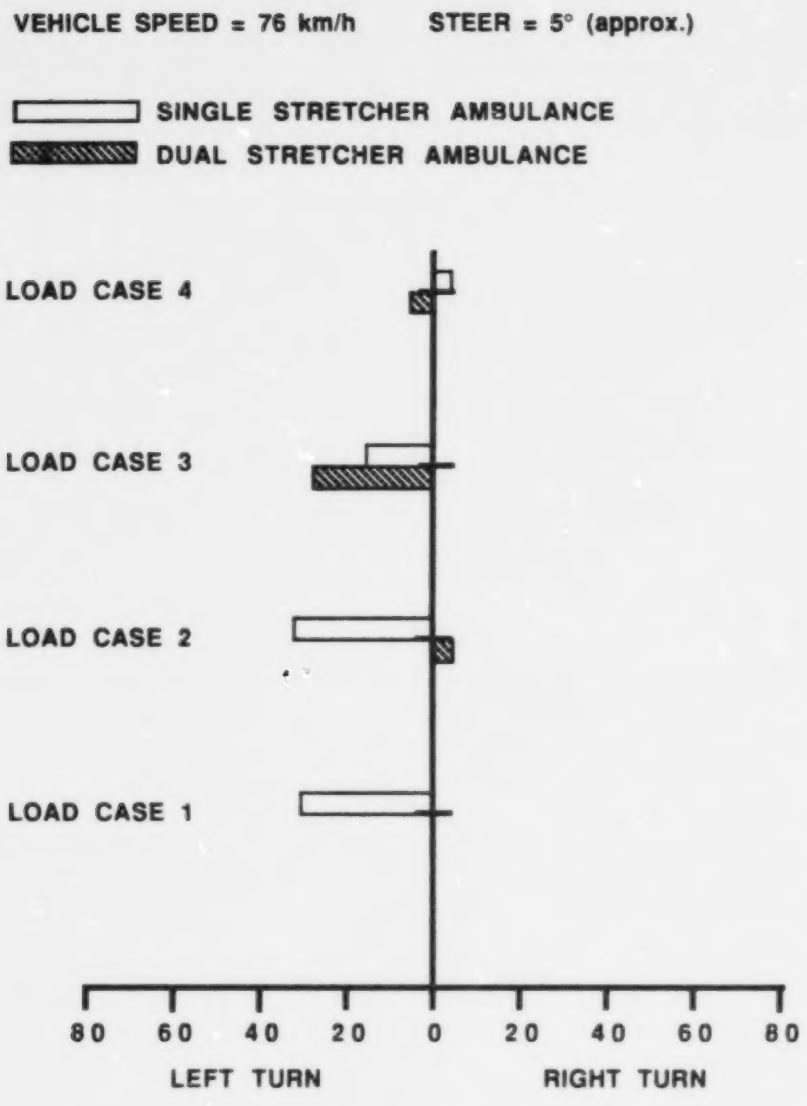


Figure 33/ Directional Response Comparison for High Speed J-Turn

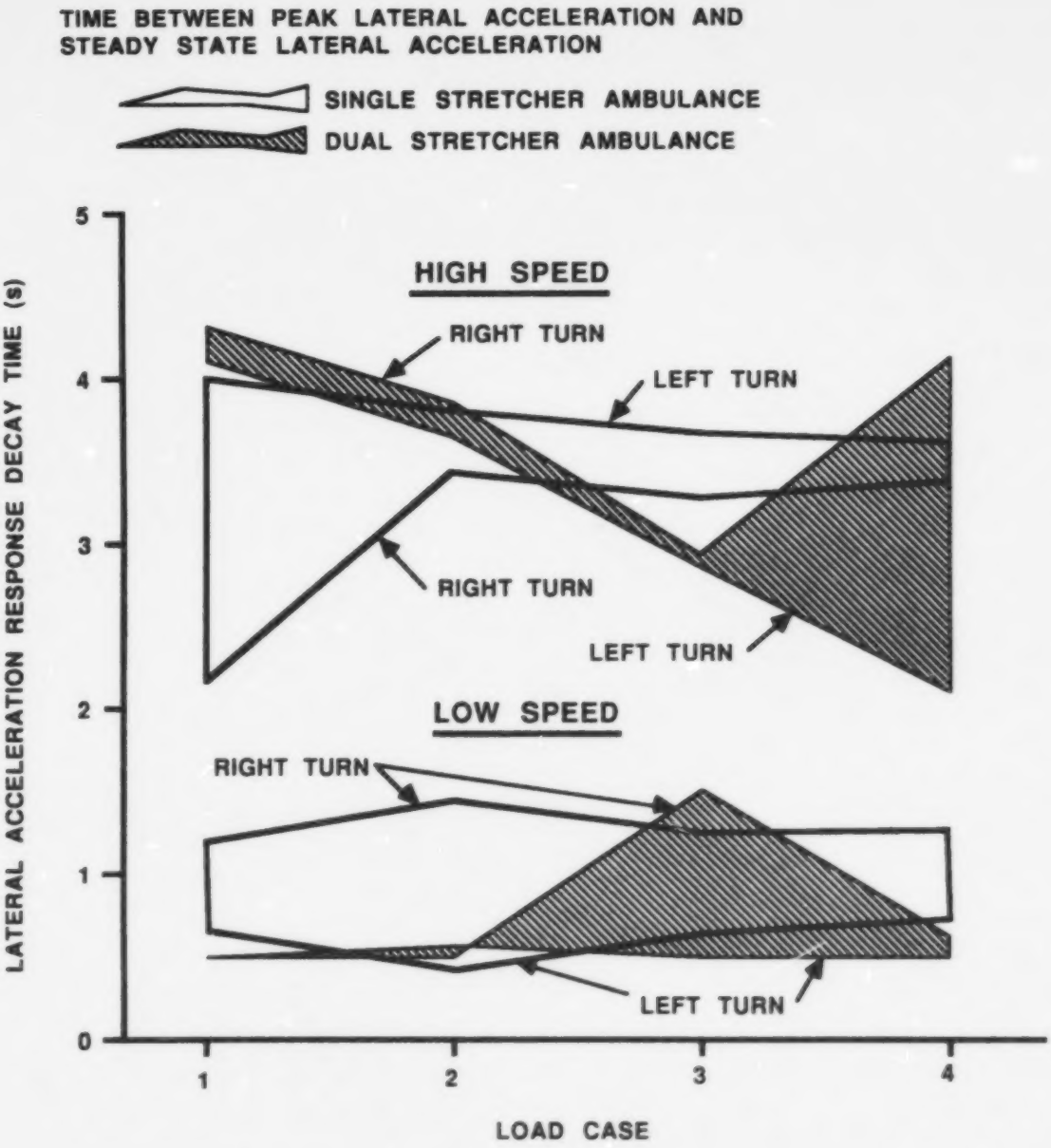


Figure 34/ Lateral Acceleration Response Decay Time for J-Turn

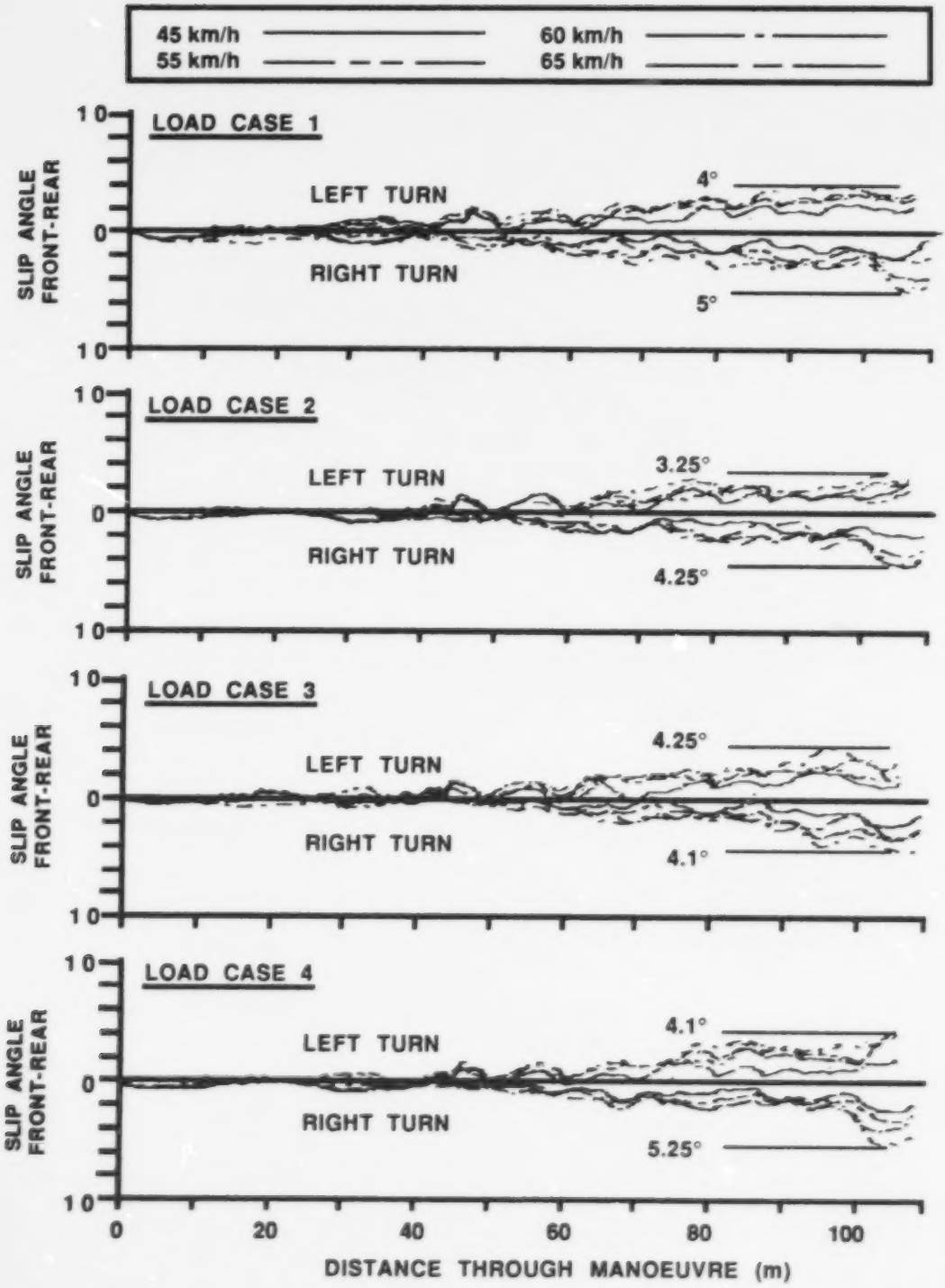


Figure 35/ Slip Angle Difference for Dual Stretcher Ambulance on Spiral Turn Course

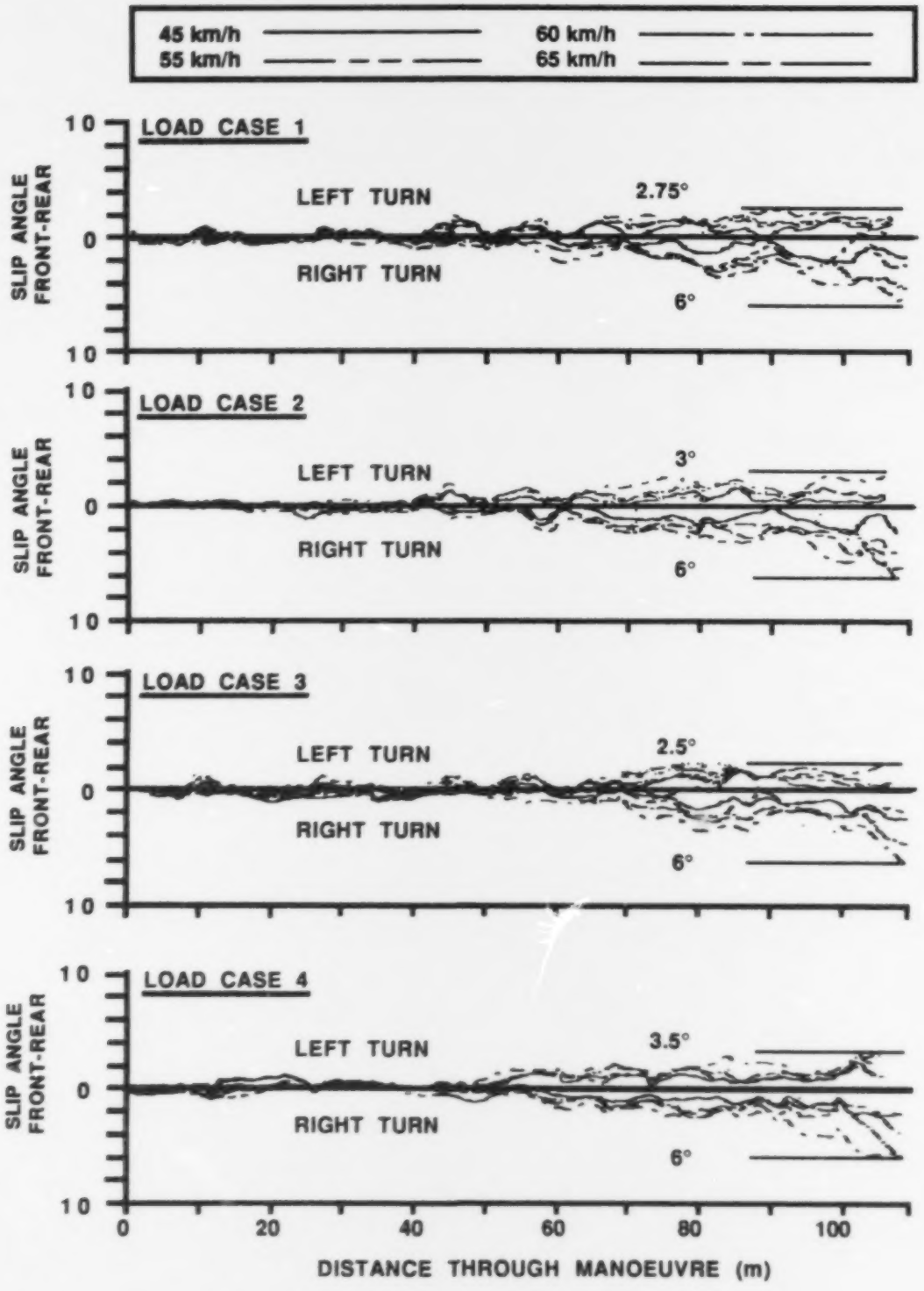


Figure 36/ Slip Angle Difference for Single Stretcher Ambulance on Spiral Turn Course

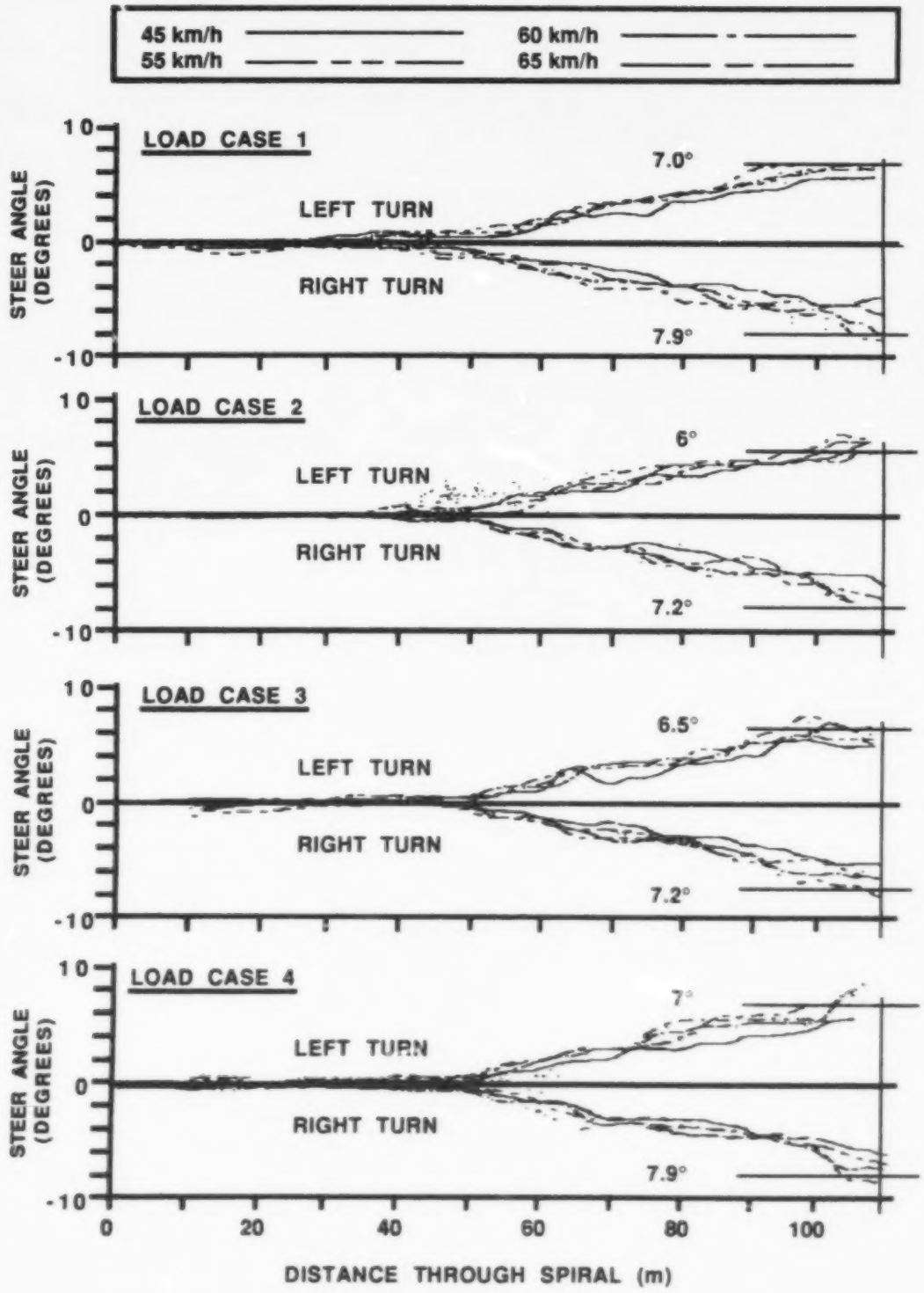


Figure 37/ Roadwheel Steer Angles for Dual Stretcher Ambulance on Spiral Turn Course

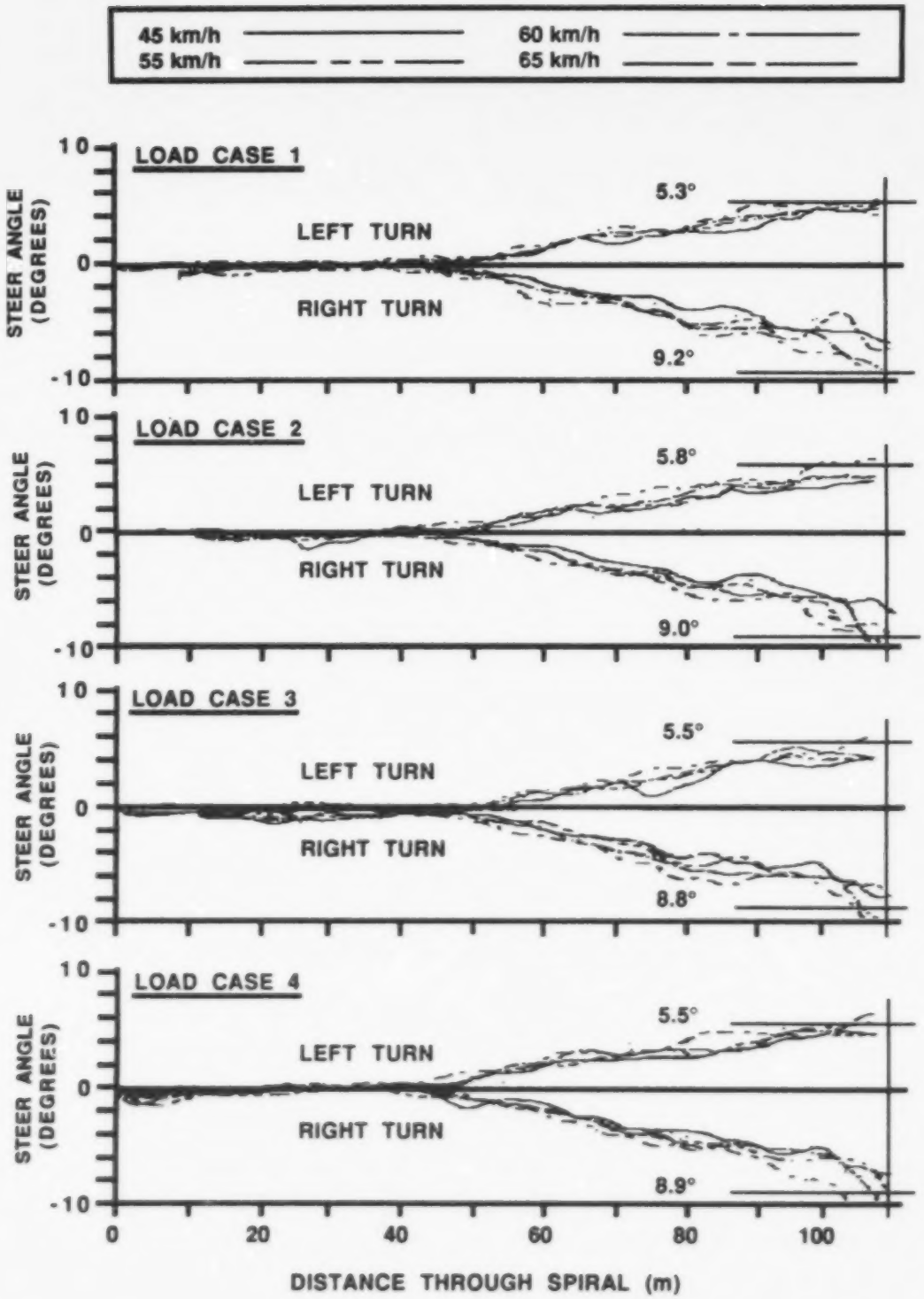


Figure 38/ Roadwheel Steer Angles for Single Stretcher Ambulance on Spiral Turn Course

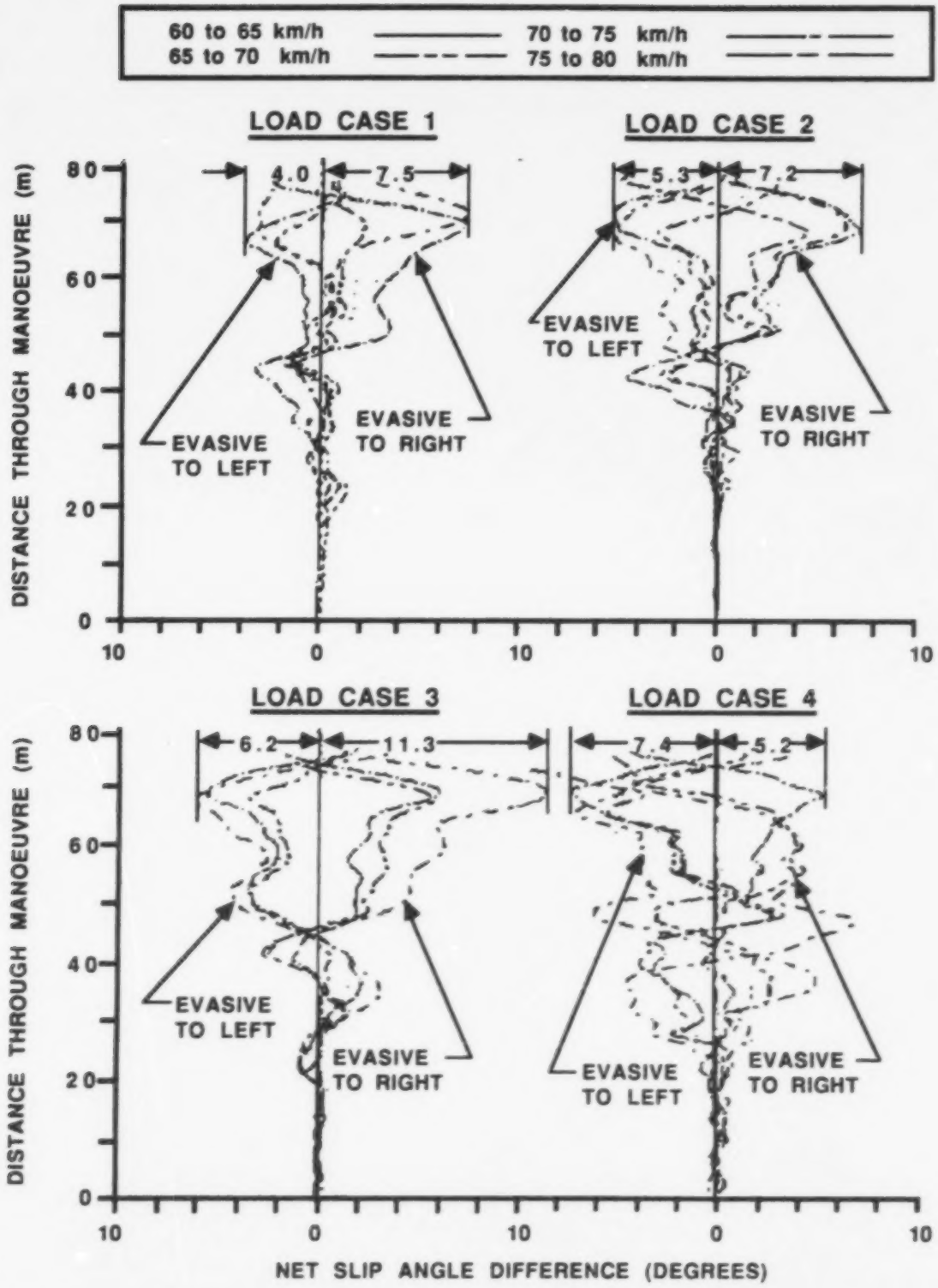


Figure 39/ Rear Axle Sideslip for Dual Stretcher Ambulance During Left and Right Obstacle Avoidance Manoeuvre at Four Speeds

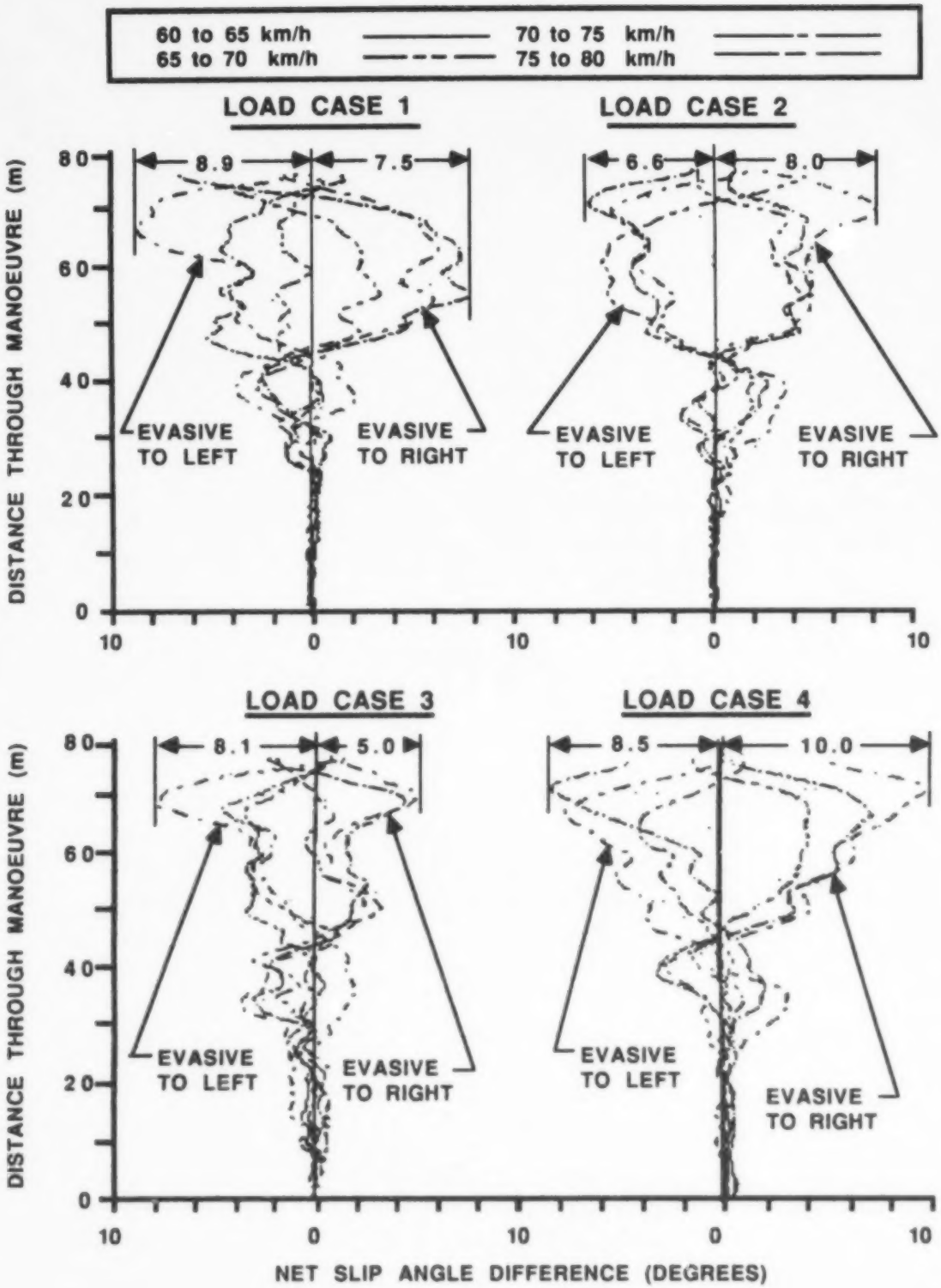


Figure 40/ Rear Axle Sideslip for Single Stretcher Ambulance During Left and Right Obstacle Avoidance Manoeuvre at Four Speeds

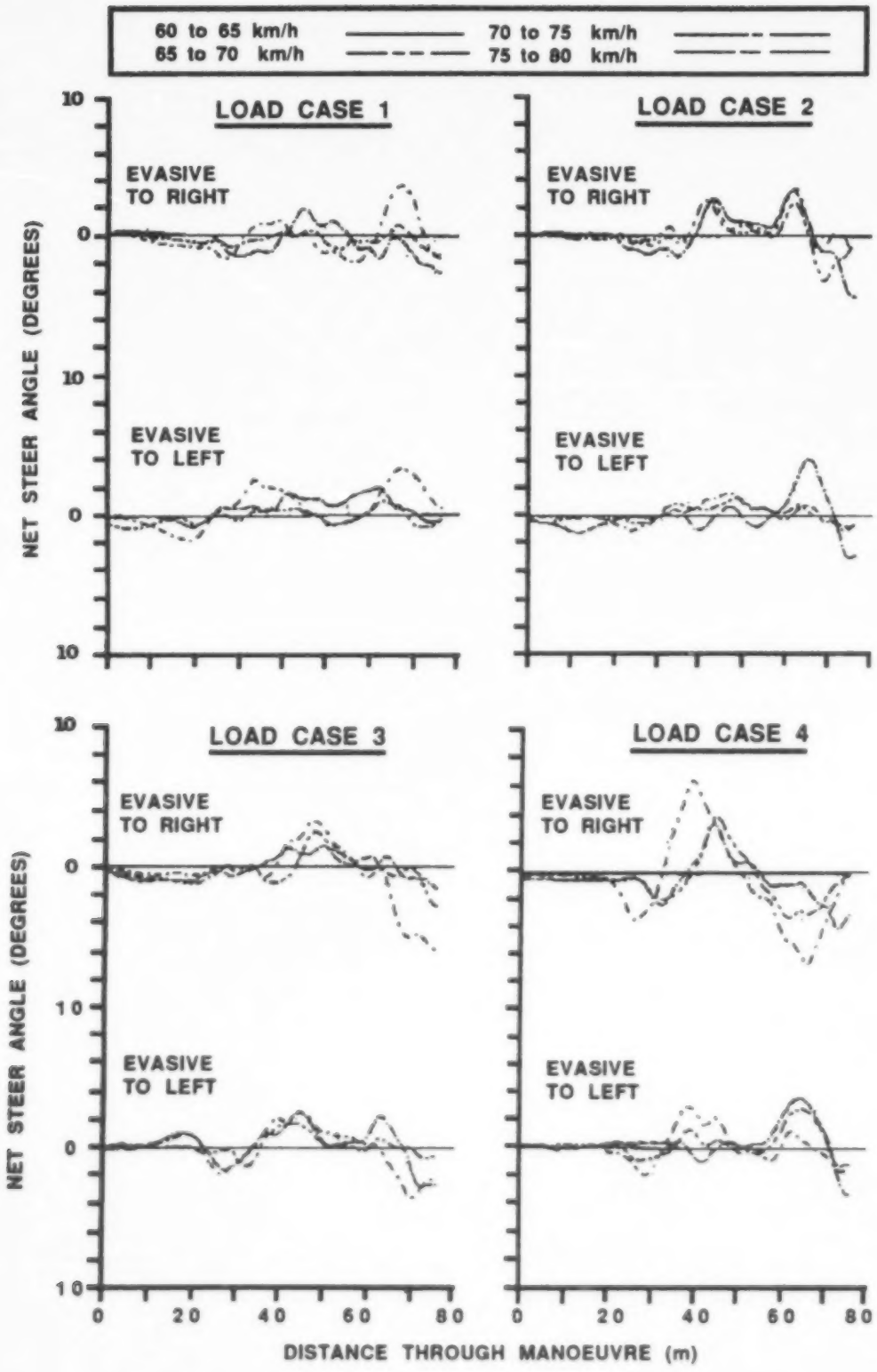


Figure 41/ Net Steer Angle for Dual Stretcher Ambulance During Left and Right Obstacle Avoidance Manoeuvre at Four Speeds

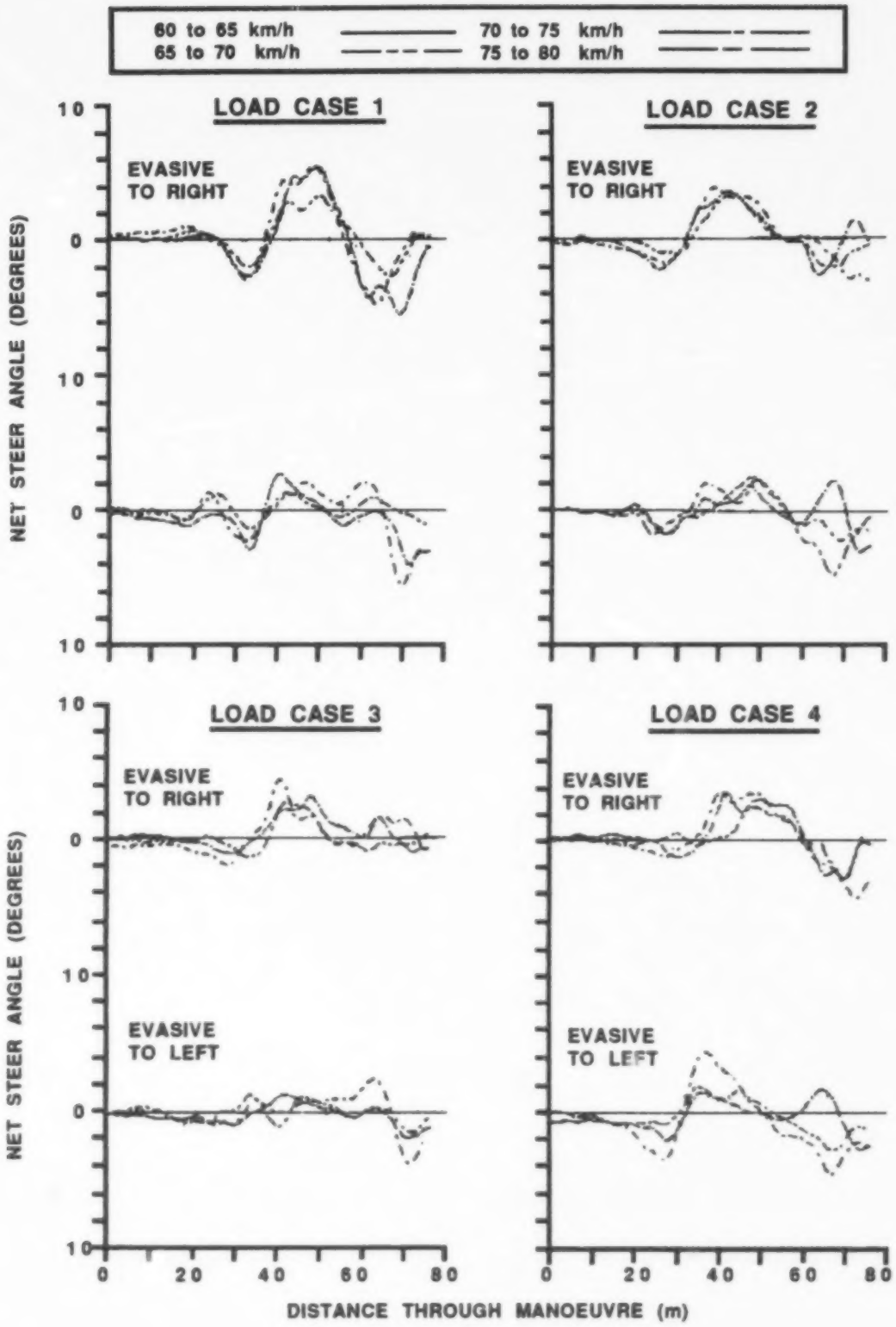


Figure 42/ Net Steer Angle for Single Stretcher Ambulance During Left and Right Obstacle Avoidance Manoeuvre at Four Speeds

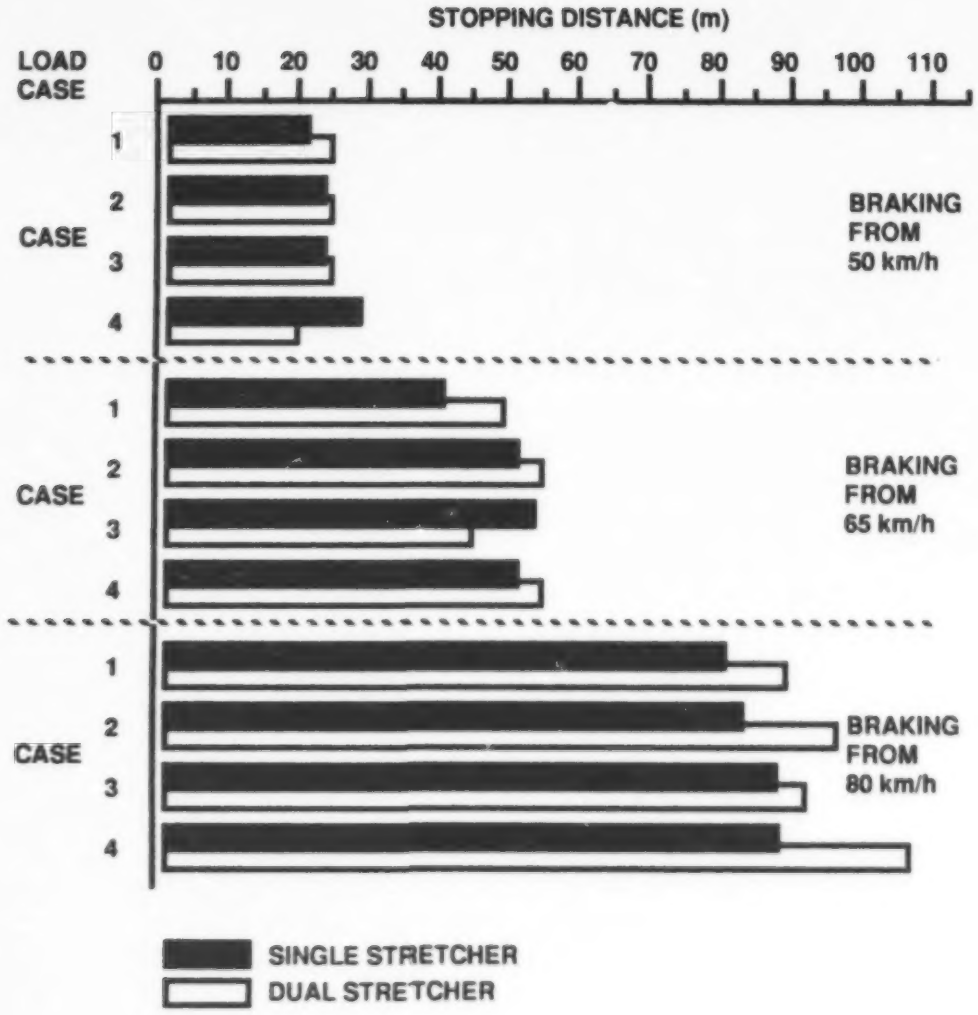


Figure 43/ Stopping Distance Comparison Between Single and Dual Stretcher Ambulances with Four Load Cases on Low-Friction Surface

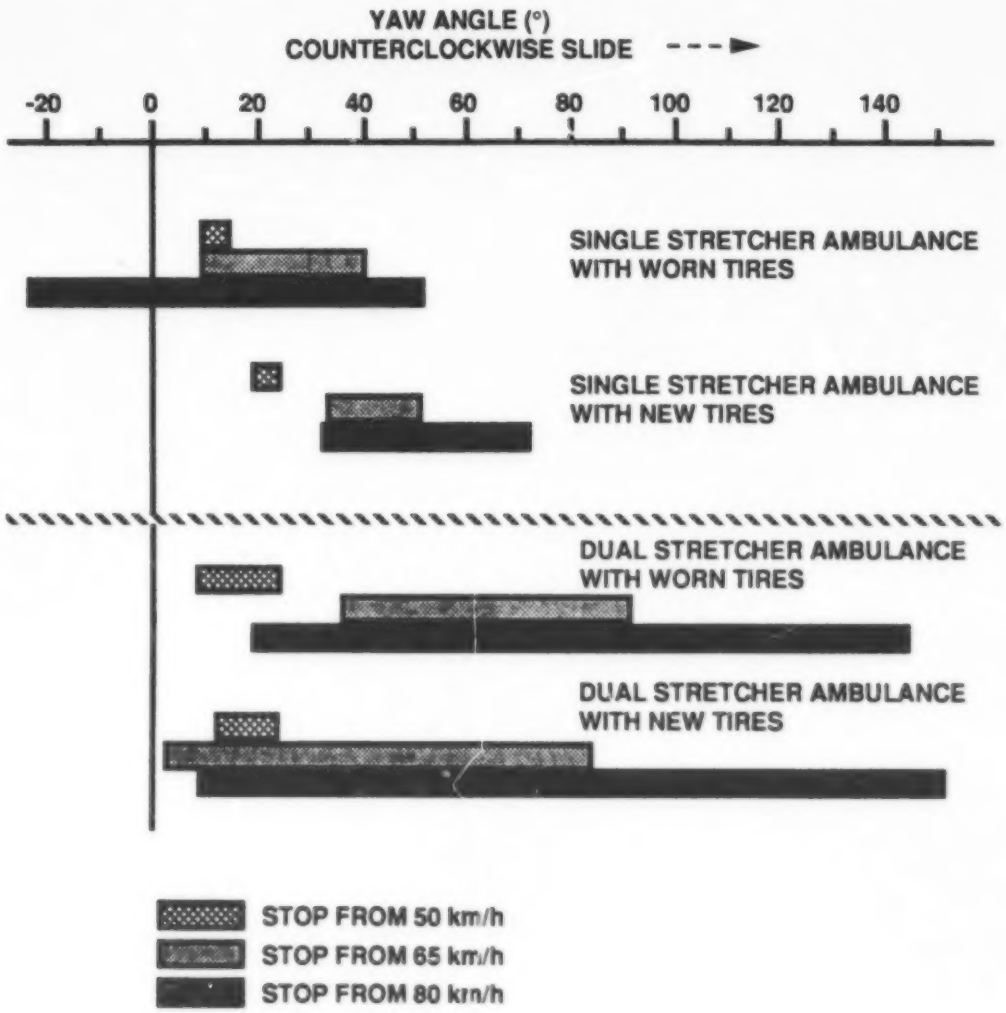


Figure 44/ Relationship Between Maximum Yaw Angle Range During Abrupt Braking on Low-Friction Surface and Vehicle Speed

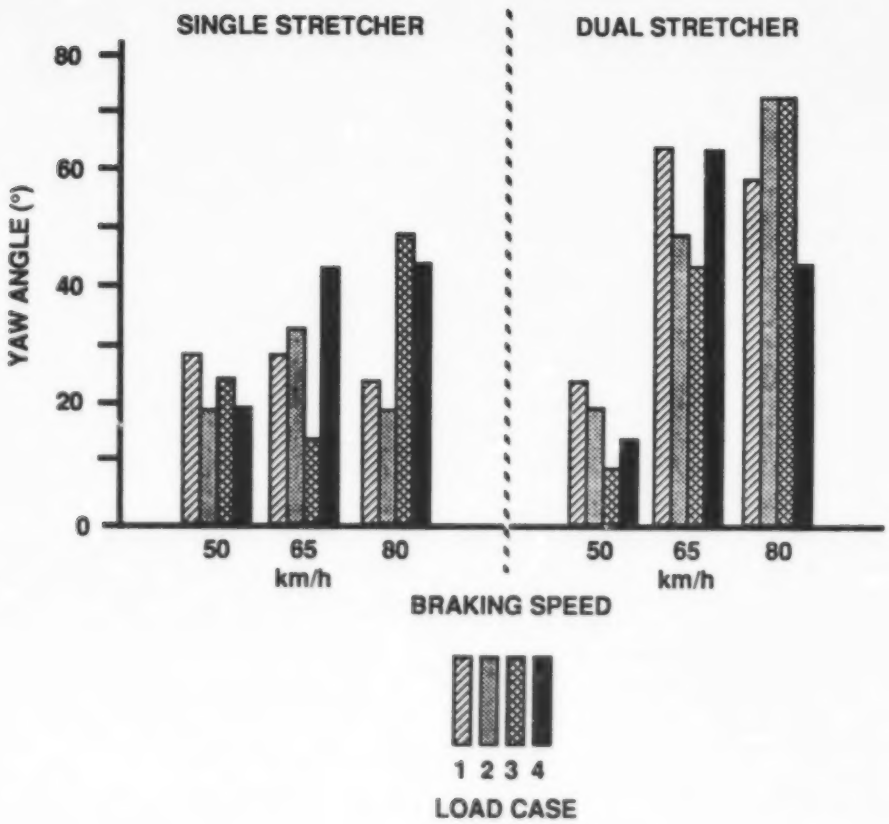


Figure 45/ Average Maximum Yaw Angle at End of Braking Slide on Low-Friction Surface (All Yaw Counterclockwise) for All Load Conditions at Three Braking Speeds

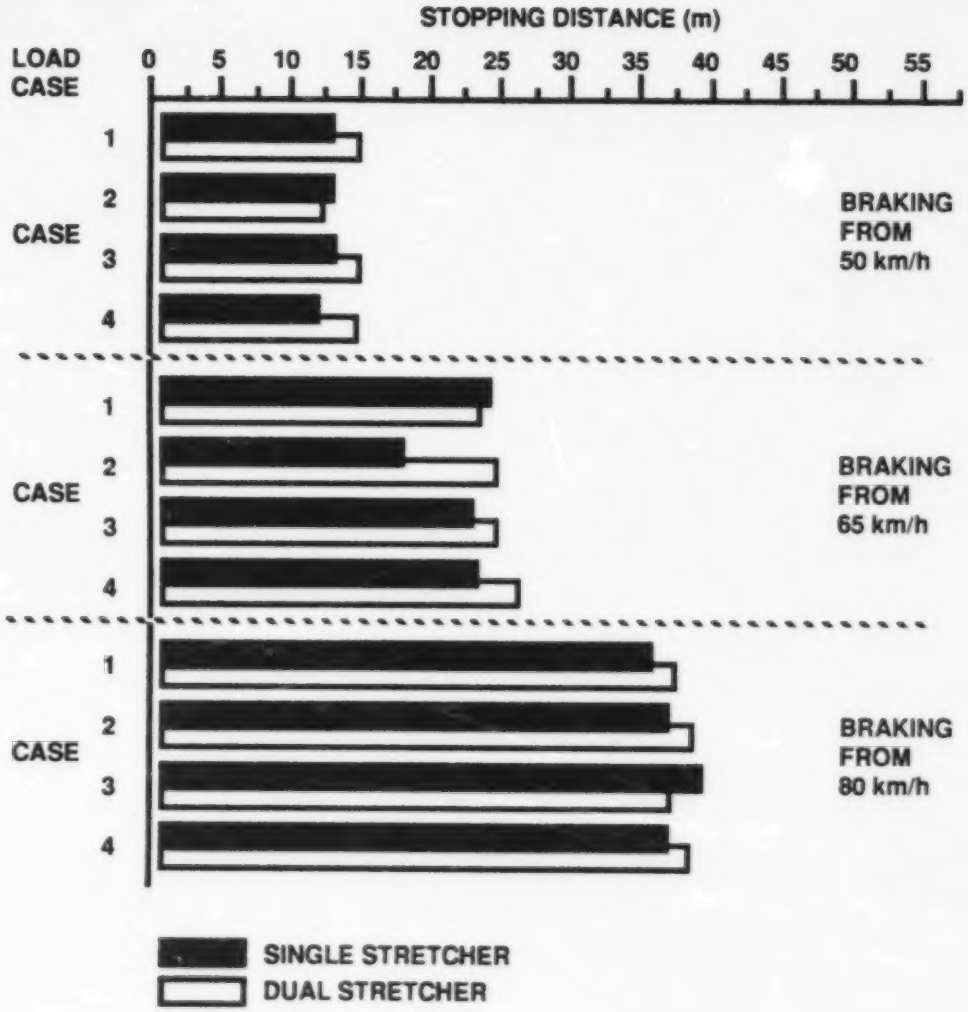


Figure 46/ Stopping Distance Comparison Between Single and Dual Stretcher Ambulances with Four Load Cases on High-Friction Surface

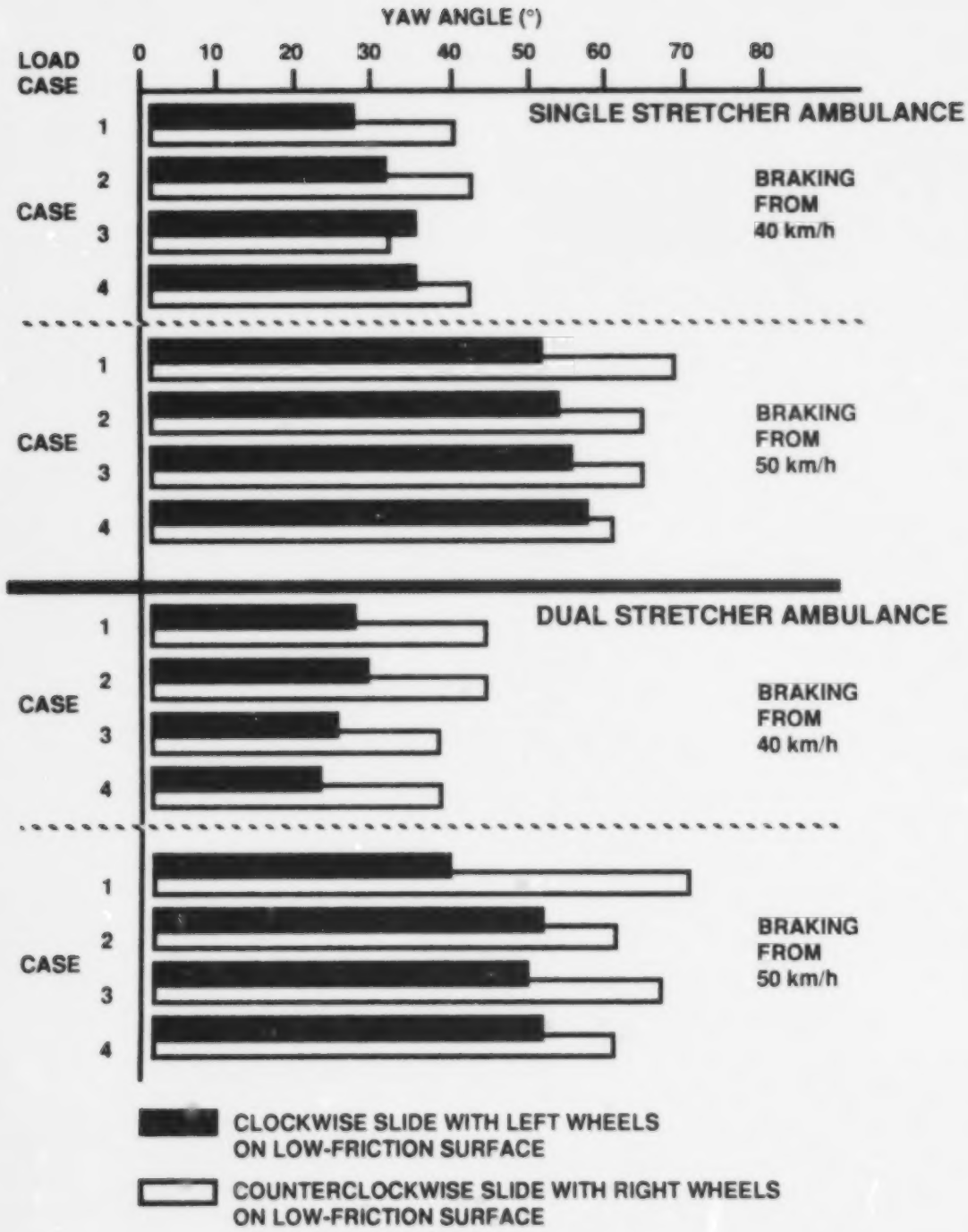


Figure 47/ Maximum Average Yaw Angles Between New and Worn Tires on Split-Friction Surface

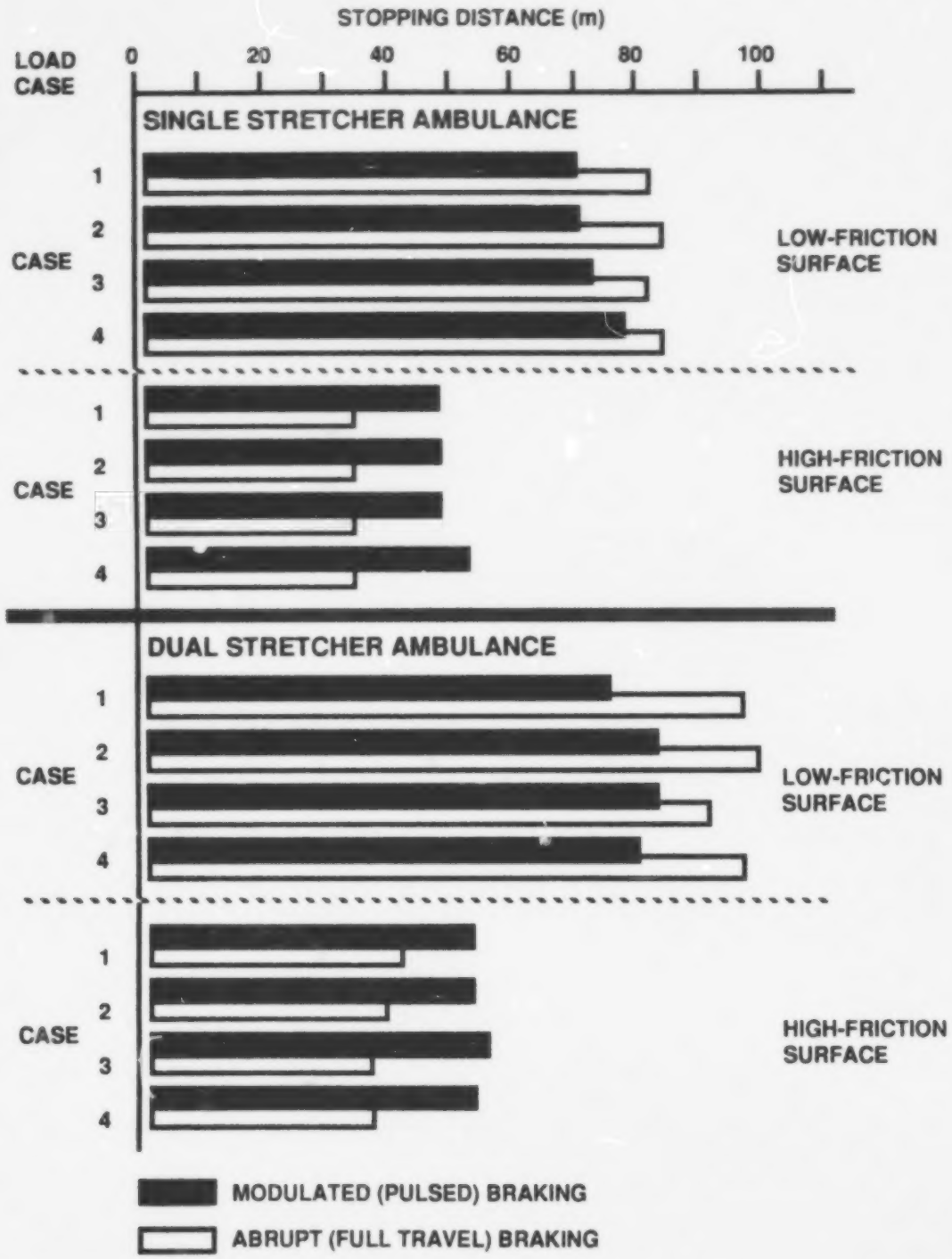
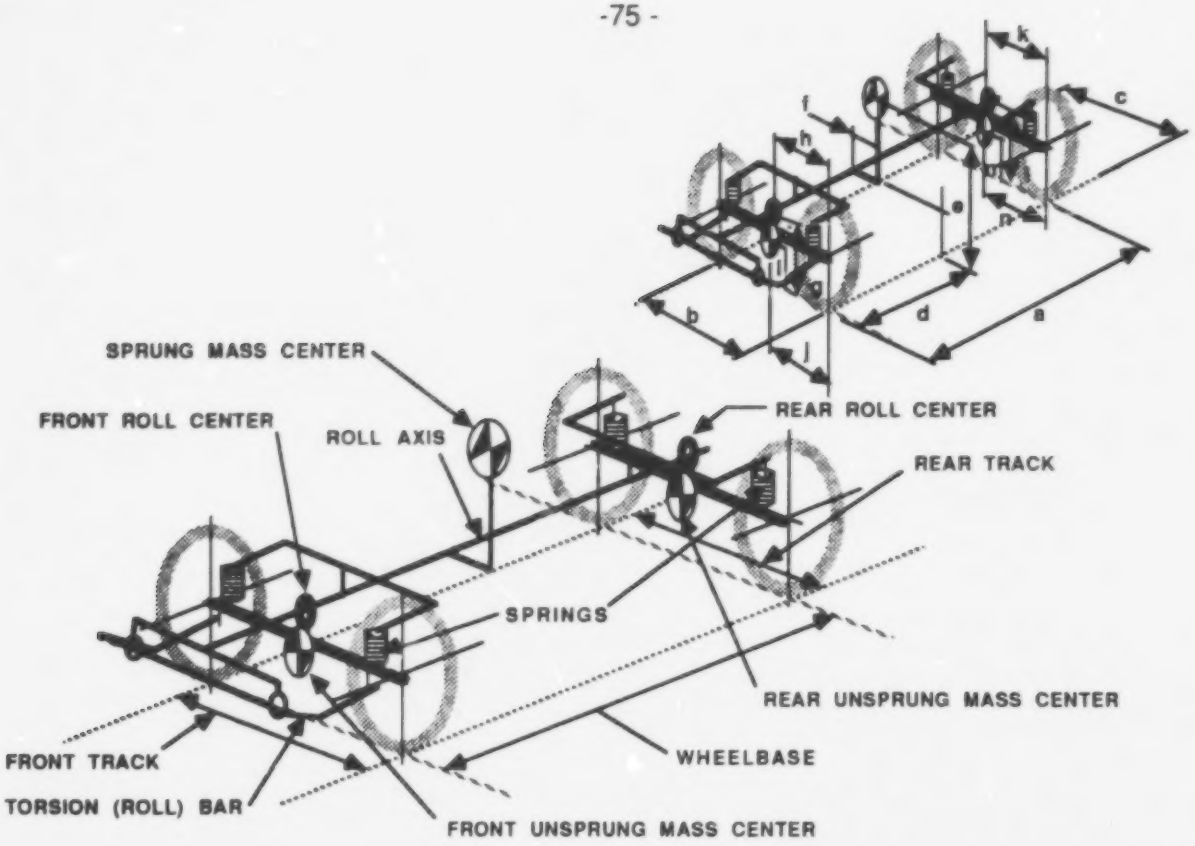


Figure 48/ Comparison Between Modulated and Abrupt Braking Techniques on Low- and High-Friction Surfaces From 80 km/h



Measurement			SINGLE STRETCHER				DUAL STRETCHER			
			Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
a	Wheelbase	(m)	3.248				3.248			
b	Front Track Width	(m)	1.73				1.73			
c	Rear Track Width	(m)	1.63				1.63			
d	Dist from front axle to CG	(m)	1.76	1.82	1.82	1.84	1.77	1.84	1.87	1.83
e	CG height	(m)	0.86	0.85	0.87	0.87	0.83	0.86	0.82	0.84
f	CG offset (left +)	(m)	0.037	0.035	0.078	-0.016	0.056	0.064	0.057	0.039
g	Front Roll Center height	(m)	-0.29				-0.29			
h	Dist from LF wheel to Roll Ctr.	(m)	0.86				0.86			
i	Front US Mass CG height	(m)	0.33				0.33			
j	Front US Mass dist from LF wheel	(m)	0.86				0.86			
k	Dist from LR wheel to Roll Ctr.	(m)	0.81				0.81			
l	Rear Roll Ctr height	(m)	0.41				0.41			
m	Rear US Mass CG height	(m)	0.33				0.33			
n	Rear US Mass dist from LR wheel	(m)	0.81				0.81			
	Front Right Roll Stiffness	(kN-m/r)	29.56				20.96			
	Front Left Roll Stiffness	(kN-m/r)	24.53				20.14			
	Rear Right Roll Stiffness	(kN-m/r)	7.82				7.82			
	Rear Left Roll Stiffness	(kN-m/r)	7.82				7.82			
	Sprung Weight	(kg)	2910	3000	3035	3230	3000	3068	3158	3311
	Front Unsprung Weight	(kg)	114				114			
	Rear Unsprung Weight	(kg)	182				182			
	Skidpad Radius	(m)	87				87			

Figure 49/ Constant Radius Simulation Model – Input Parameters

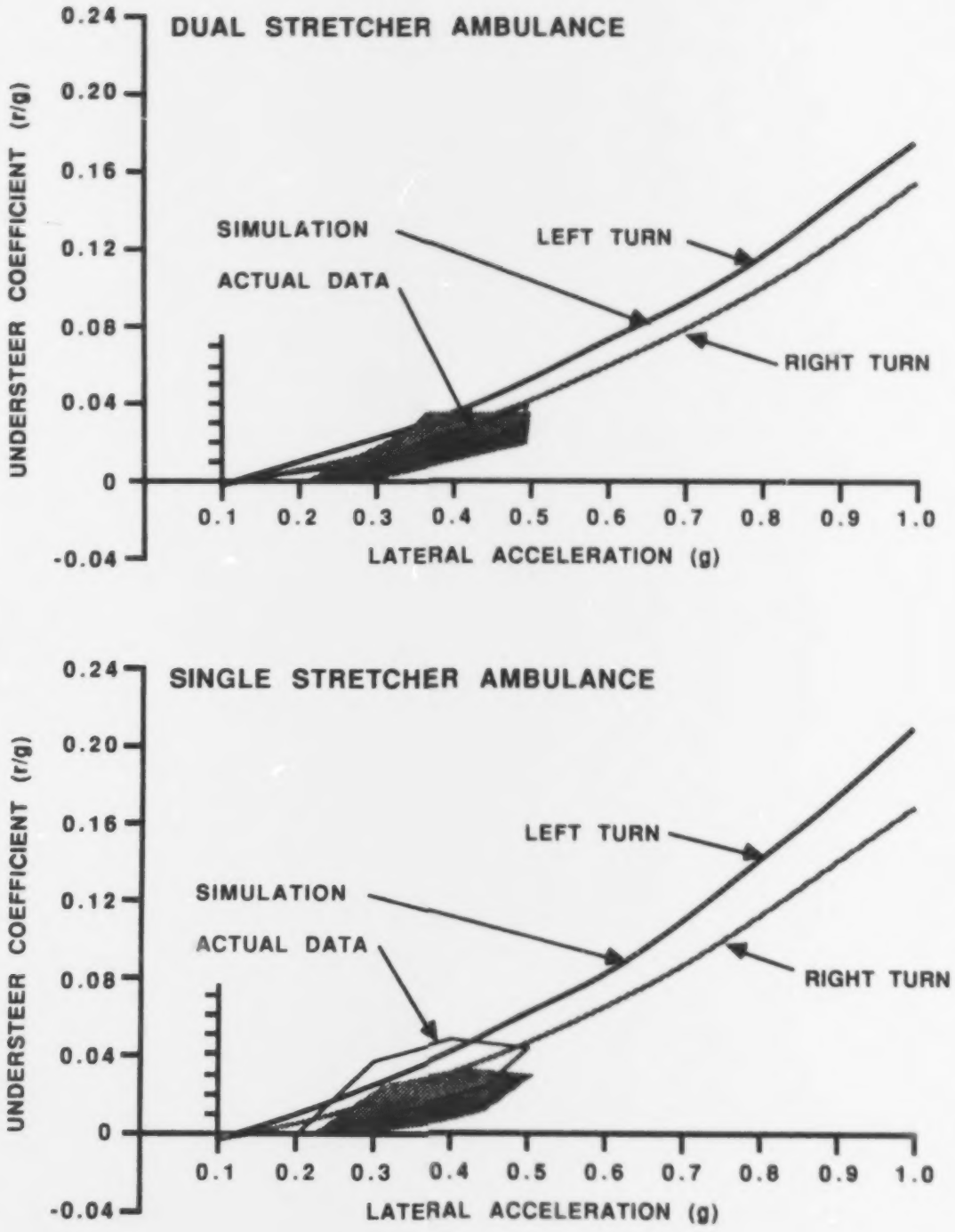


Figure 50/ Constant Radius Simulation Model Response – Compared with Test Data

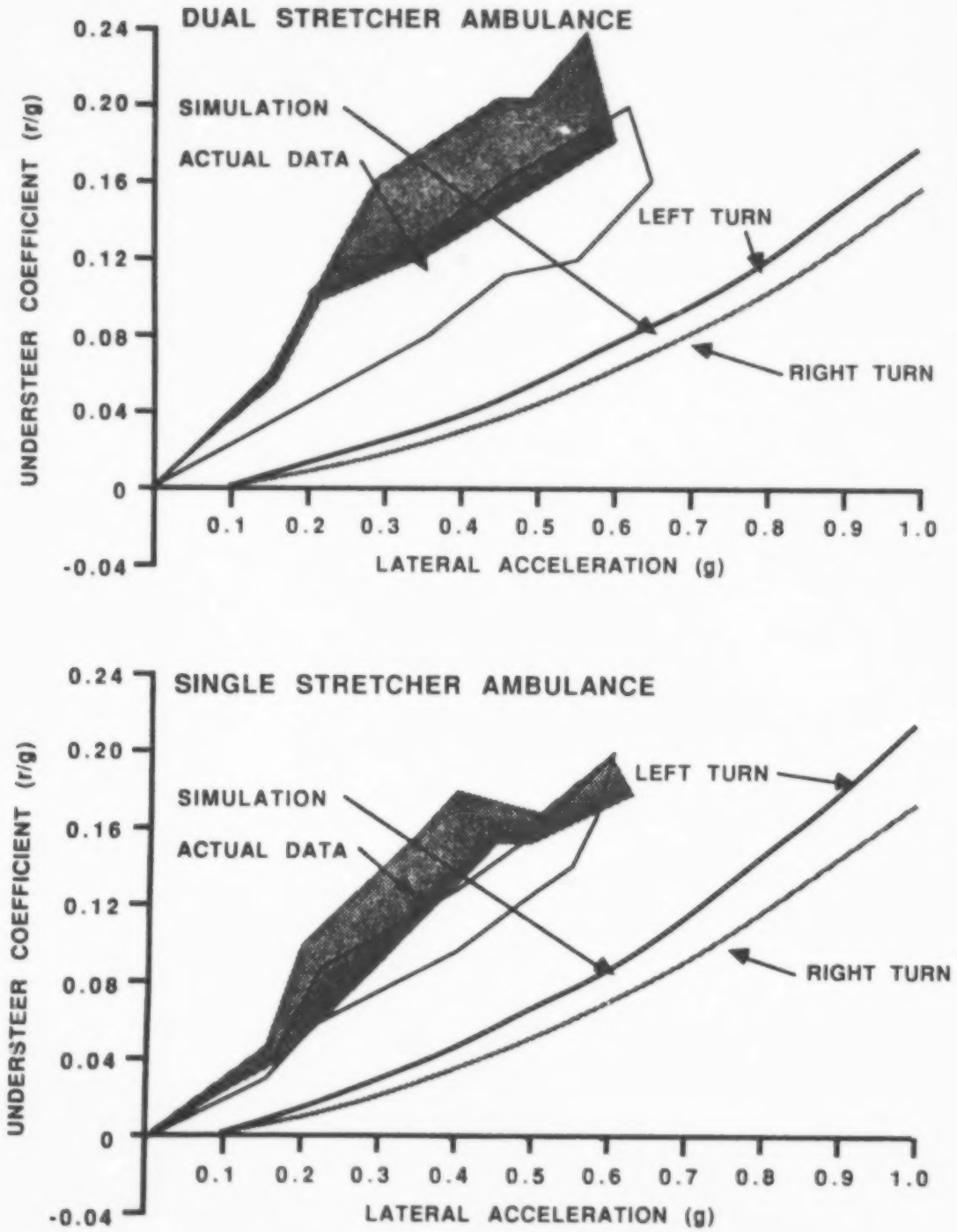


Figure 51/ Constant Radius Simulation Model Response – Compared with Constant Steer Data